# ARC WELDING
# AND
# CUTTING MANUAL

GENERAL ELECTRIC COMPANY

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GEA-208
*Old Series Y-2007*

# ARC WELDING
# AND
# CUTTING MANUAL

*The science of Electric Arc Welding is still in the developmental stage. Certain applications of the process have become fairly standard, but each day sees the Art growing and uses increasing by leaps and bounds. There are no limits to the possibilities of development along many lines.*

*The purpose of this manual is to acquaint the uninformed in a general way with some of the applications of Arc Welding, and to provide a simple and logical method by which one may acquire a certain familiarity with the manipulation of the Electric Welding Arc and its characteristics.*

*With the above objects in view, this manual has been divided into four parts. Part I contains a general treatise on Arc Welding. Part II consists of a training course for Arc Welding operators. Part III contains illustrations and explanations of some of the applications and problems of the Arc Welding process. Part IV describes General Electric Arc Welding apparatus.*

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SCHENECTADY, N. Y.

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# ARC WELDING AND CUTTING MANUAL

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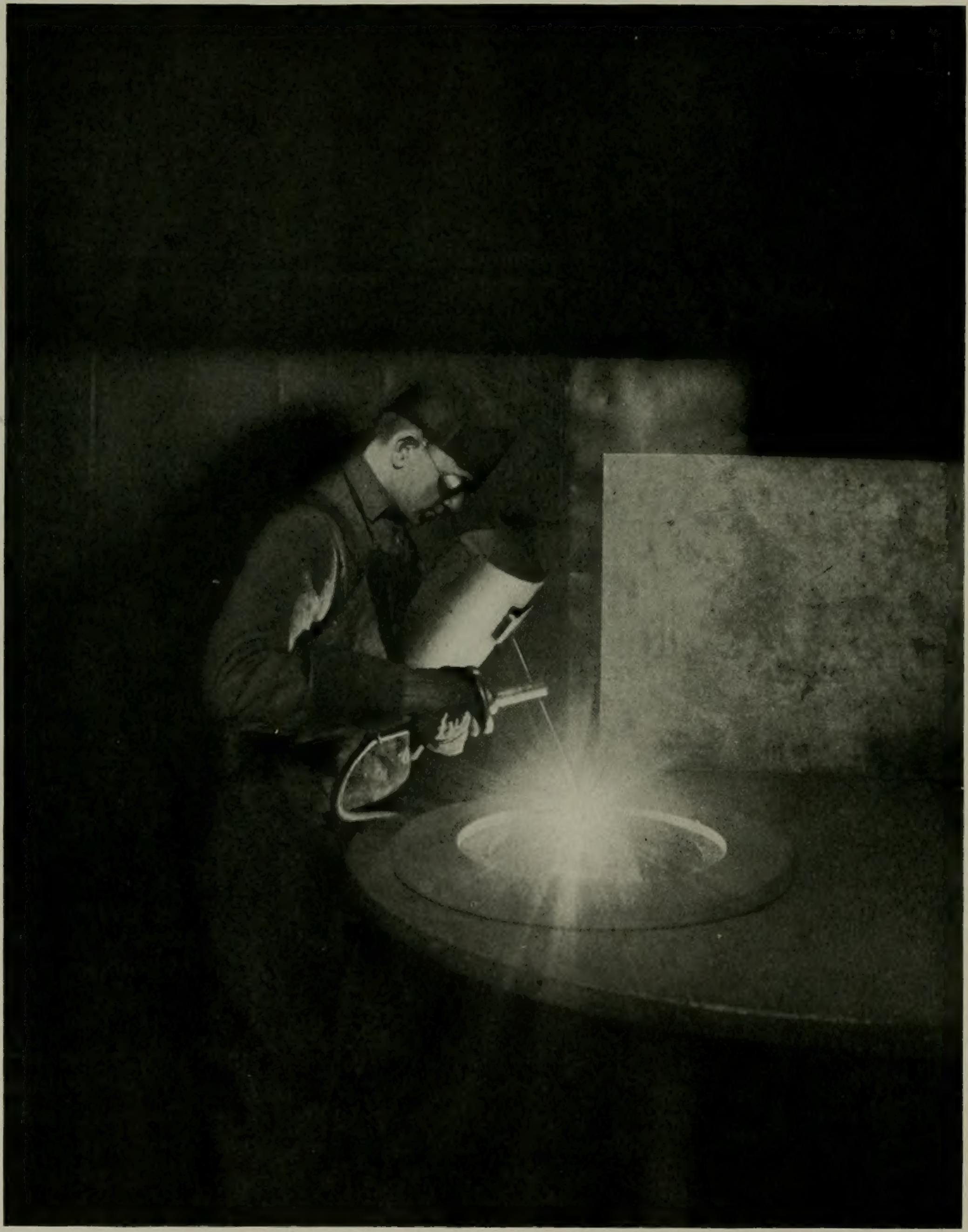


# PART I

## GENERAL INFORMATION

WELDING, by means of the electric arc, utilizes the heat liberated in the arc stream and at the terminals of an electric arc, to fuse properly the metals to be welded so they will flow together and form a solid homogeneous mass.

In welding or building up metal surfaces the arc melts a small pool of metal on the work pieces and any additional metal required is deposited from a wire or rod, which is melted by the heat of the arc, in this pool in a molten state. The heat of the arc causes the molten metal in the pool to be agitated and thus the base metal and added metal are mixed so that a firm union is formed when the weld has cooled.

When the welding arc is drawn between the metal to be welded and a metal wire electrode, the process is called "Metallic Arc Welding." When a carbon or graphite rod is used for one terminal of the arc, the process is called "Carbon Arc Welding."

For "metallic arc welding" work the electrode is simply a metal rod or wire, which supplies the filler metal. The arc is struck between the metal electrode and the work, instantly fusing the end of the electrode and carrying this metal to the work, forming a solid homogeneous joint. Metal can thus be deposited on vertical surfaces or in any direction and the metallic electric arc provides by far the best means by which metal can be successfully deposited overhead.

In the method known as "carbon arc welding" the electrode consists of a carbon or graphite pencil, the additional metal required by the weld being supplied by a metal filler rod which is melted in the arc.

The metallic electrode process requires a comparatively low energy input. The metal deposited is more likely to be homogeneous and a weld so made has a smoother and more regular appearance than one made by the carbon electrode. For these reasons the metallic electrode is very extensively used.

The carbon electrode method is often used for building up metal, plugging holes in castings, welding and joining parts where appearance is not essential and speed is desirable. See page 58. Metal can be built on by melting from a rod of filling material in a manner similar to soldering with an iron, or welding with a gas torch.

For cutting or melting away excess stock, the carbon or graphite electrode is used. In cutting, the arc is held stationary at the start of the cut until the metal begins to flow. As the metal melts and runs off, the arc is advanced making a cut through the piece. See Fig. 59 and 60. It is necessary that the material which is being cut be placed in such a position that the molten metal will easily and quickly flow out of the path of the arc.

Since the welding of medium carbon steel is the principal field of the welding arc in general, the comments which follow refer to the welding of this metal. The application to other metals will be referred to specifically in any discussion.

Welds soft enough to be machined can be made by either method if reasonable care is taken. The deposited metal should not be chilled, and if the carbon or graphite electrode is used the arc should be long enough to prevent carbon being carried into the weld. Other causes of hard welds are usually poor quality of electrode or filling metal, or contamination of the weld by foreign matter.

The deposited metal is obviously cast steel, since it is merely fused in place and is not ordinarily subjected to any mechanical working afterward. This metal will therefore have the coarse crystalline structure found in unannealed cast steel and likewise will have comparatively low values for reduction of area and elongation when specimens are tested in a tensile testing machine. In some cases the tensile strength of the metal in the weld may be as high as 55,000 to 60,000 pounds per square inch. A safe figure is 35,000 pounds per square inch where the work is done by experienced welders, since a good welder can consistently produce welds having a strength of at least 40,000 pounds per square inch.

### THE ELECTRIC WELDING ARC

An arc is formed by current flowing across a gap in an electric circuit. A small amount of the material, forming the terminals of the arc gap, is heated to an incandescent vapor. This vapor provides the material in the arc stream by which the current passes from one terminal to the other.

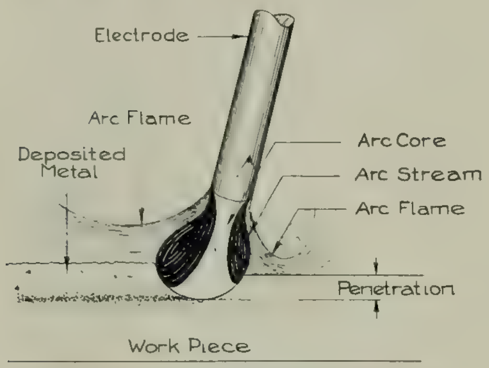


**Fig. 1. DIAGRAM OF THE WELDING ARC**

The terminal from which the current passes to the arc is termed the positive terminal or electrode, or the anode, and the terminal to which the current passes from the arc is called the negative electrode, or cathode. The exact distribution of the heat in the arc between the two electrodes and the arc stream is still unknown. It is, however, a matter of general knowledge that the greater portion of the total heat of the arc is liberated at the positive electrode.

When direct current is used, one terminal remains the positive continually and the greater portion of the total heat is liberated at this terminal. When, however, alternating current is used, the terminals are alternately positive and negative so that approximately the same amount of heat is liberated at each terminal. In direct-current welding circuits the positive is usually called the ground lead or ground terminal.

#### Polarity

Usually the piece of metal to be welded is considerably larger and has more mass than the electrode so that the loss of heat at this point will be greater due to its being conducted back into the body of the metal. Consequently, it is desirable to have more heat liberated at this point to make up the losses and to bring the temperature of the metal to the fusing point at the same time that metal is fused and deposited from the electrode. For this reason direct current is generally used for arc welding, and in the welding of iron or steel the piece to be welded is usually made the positive terminal of the arc. In case, however, very thin metal is being welded, it is frequently advisable to reverse the polarity to prevent the arc burning through the metal. In the welding of some metals, such as manganese steel, bronze, etc., it is often necessary to reverse the polarity and make the electrode positive.

The polarity of a circuit can be determined in a number of ways. The simplest and most positive way is to determine it by means of a voltmeter. Another method is to draw an arc between either a bare metallic electrode or a carbon electrode and a steel plate. If the plate is positive and the electrode negative, the arc will be fairly stable. If, however, the circuit is reversed and the electrode is positive, the electrode will heat up very rapidly and the arc will become "wild" or it will flutter and will be hard to keep going. With reversed polarity the penetration with the metallic electrode is poor and the deposited metal can be very easily knocked loose.

### Source of Welding Current

Welding current can be obtained from any electric circuit of sufficient voltage, but usually a special low voltage direct-current generator is used in order to keep down the losses involved in reducing the voltage to the value required by the arc.

Two general types of equipment are used, being commonly referred to as the constant potential and the constant energy types. See Part IV, pages 130–133. As indicated by the name, the constant potential generator delivers a constant direct-current voltage, regardless of the current drawn, up to the capacity of the generator. The voltage of such a circuit will run from 35 to 75 depending upon the type, but the average value is around 60. In order to reduce the voltage to that required by the arc a resistor is connected in the line, usually between the supply circuit and the electrode holder. Consequently, each welder must be provided with such a resistor and by changing the value of this resistance the current in this individual circuit can be adjusted as desired.

The constant energy type of generator is specially wound so that the voltage falls as the current increases. With this type of equipment a separate generator is required for each welder. The open circuit voltage on this type of generator is practically the same as that of the constant potential type. No resistor is required in this case since the generator will automatically reduce its voltage as the current in the arc tends to increase. Either type of generator may be driven by any source of power, but usually an electric motor is used. The use of a motor-generator set separates entirely the power circuit and the welding circuit so that the welder is only concerned with the low voltage welding circuit. This voltage is so low that there is no danger to the operator.

For metallic arc welding by hand the usual range of arc current used is from 50 to 300 amperes at an arc voltage of approximately 20 to 30 volts. For some classes of work, current values as high as 350 amperes can be employed. For carbon arc welding the arc current may be from 25 to 600 or more amperes, at a voltage of approximately 40. For cutting, the current may be as much as 1250 amperes.

There is usually provided, by the manufacturer, with each welding generator or equipment a set of instructions for its care and adjustment. The welder should study these instructions until they are understood, since the adjustment of the current and voltage is a very important factor in welding.

## CHARACTERISTICS OF THE WELDING ARC

The temperature of the vapors in the arc and, consequently, the intensity of the light given out is so great that darkened glass must be used in order to observe the arc. When suitable glass is used, the different portions of the arc can plainly be distinguished from one another. The center of the arc is usually referred to as the arc core and some observers are able to see that this is divided into two portions designated as "arc core" and "arc stream." In general, this portion of the arc will usually be seen as greenish in color, of comparatively small diameter and forming a direct line between the two terminals of the arc. The point where the arc core strikes on either terminal is seen as a light red or yellowish spot considerably bright and, therefore, hotter than the metal surrounding it. The metal around this spot is molten and is usually seen as a bright red area. This color gradually shades off into darker red with lower temperatures and finally becomes black at a short distance, not over ½ in. from the arc, except in the case of very heavy welding. Slag, oxides, etc., can be distinguished floating on the molten metal either as light or dark spots, depending upon the melting point of the impurity. Surrounding the arc core is the arc flame which is irregular in shape and in constant motion, being easily deflected by magnetic fields due to the current in the electrode and in the plate and also by drafts which may arise by reason of the heat in the arc or by exposure to wind, etc.

### Penetration

At the point where the arc strikes the plate, assuming that current, polarity and speed of travel are correct, the metal is melted and seems to be forced out of the pool by some sort of blast from the arc. This results in the metal piling up around the edges of a small depression in which the metal is in a molten stage. This depression is referred to as the arc crater and its depth provides a means of observing the penetration during welding and, to a certain extent, of predicting the soundness of the weld since one requirement of a weld is to secure good penetration. The crater depth will depend upon the thickness of metal welded, but in general should be at least $\frac{1}{16}$ in.

Correct penetration will make certain that the metal of the plate is melted and in condition to receive the metal projected from the electrode, also that the area of the crater will be sufficient to receive all the metal from the electrode and not permit any of the deposited metal to overlap on the solid metal of the plate where it will not stick.

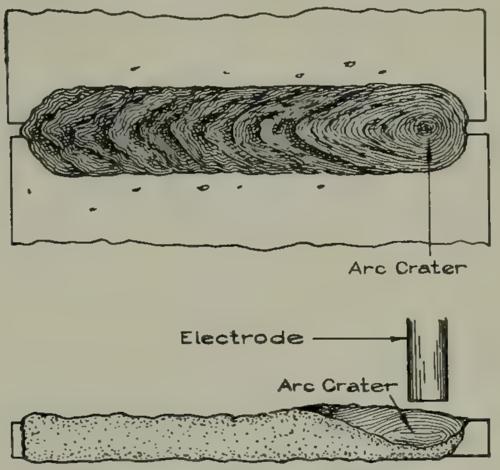
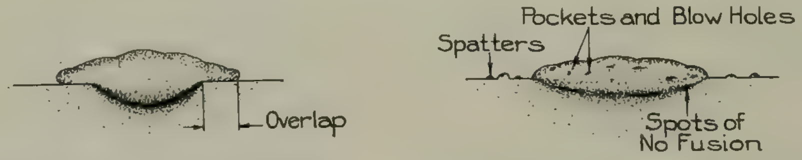


Fig. 2. LONGITUDINAL SECTION OF DEPOSITED METAL SHOWING PENETRATION AND ARC CRATER

### Arc Length

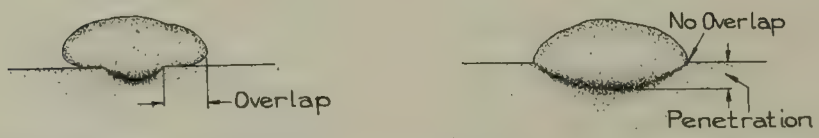
While the correct arc length alone will not insure good welds, it is agreed that a long arc is almost certain to result in a poor weld. The plate or work is heated by the release of energy at the terminal of the arc, by radiation and conduction from the arc core and stream, and by radiation from the hot surface of the electrode and the hot metal deposited on it. With a short arc this heat is concentrated on the plate, whereas with a long arc a great deal of it is lost into the surrounding space. Consequently, with a short arc a greater portion of the energy is transformed into useful heat.

A long arc is not as stable as a short arc and tends to wander about over a considerable area on the plate and the arc flame blows about very rapidly. This action together with the



(a) Welding arc has traveled along too slowly

(b) Too long arc used or too rapid travel



(c) Not enough heat used

(d) Weld which is satisfactory

Fig. 3. CROSS SECTIONS OF BEADS DEPOSITED UNDER DIFFERENT CONDITIONS

greater length of the arc, affords considerable opportunity for the air to come in contact with the metal passing from the electrode to the plate and also in contact with the very hot metal in the arc pool or crater. This results in the absorption of oxygen and nitrogen, both of which are detrimental to the quality of the weld. With a short arc, the flame consisting of vapors coming out of the arc acts as a protection and prevents very largely the absorption of these outside gases.

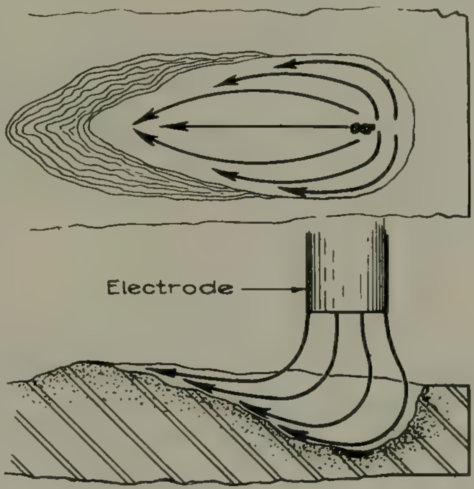


Fig. 4. DIAGRAM SHOWING FLOW OF WELDING METAL WHEN WELDING

The expression "short arc" really means very little since it is greatly affected by the electrode diameter and current used. With a ¼ in. diameter electrode and 250 amperes or more, the arc will be from $\frac{3}{16}$ to ¼ in. in length and the arc voltage will be from 18 to 26 volts. If, however, a $\frac{1}{16}$ in. electrode is used with a current of 40 amperes the arc length may be less than $\frac{1}{16}$ in. and the arc voltage from 15 to 18. In general, the arc should be held just as short as it is possible to hold it without causing the electrode to touch the work and to put out the arc. Experience will teach the operator to tell by observation when a short arc is being held. It is possible to tell by sound, with low carbon steel electrodes, whether the arc is long or short. If the arc makes a rapid crackling sound that is fairly steady in intensity, the arc is short. The sound of a short arc is very much like the frying of grease in a pan. If the arc makes a hissing sound punctuated by explosions occurring at intervals of from ½ to 1½ seconds, the arc is too long. A short arc throws a steady shower of small sparks, whereas each of the explosions caused by the long arc scatters a considerable number of larger globules of metal.

The above discussion refers to the metallic arc or the arc between a metal electrode and the metal of the piece being welded. When a carbon arc is used for welding, it should be from ¼ to 1½ in. long and should have a slight hissing sound. In cutting, the arc should be shortened to about half this value in order to concentrate the heat and will apparently become unstable and give off a hissing, squealing and snorting sound. The length of a carbon arc varies with the current used, being generally shorter with lower current. Experience will teach the proper arc length to be used under different conditions.

## Arc Stability

The current in the arc passes through a path of highly heated vapor from the materials forming the terminals of the arc. If this vapor cools, the arc will go out or will at least vary greatly in the resistance and amount of current and heat. Special metallic electrodes are often provided with coating whose function is to provide this vapor and maintain the arc, thus making it more stable. Occasionally the welder will come across steel electrodes with which it is impossible to maintain an arc due to its "wild" or unsteady action. This condition is often remedied by dipping the electrodes in lime water. On drying, a small amount of the lime sticks to the wire and this is sufficient to steady the arc and make the material useful.

A high open circuit voltage will also make the arc more stable since excess voltage is available to re-establish the arc if for any reason it starts to go out. A reactance coil in series with the arc acts in a similar manner and particularly on very light work with low currents the reactance coil is of great value.

It has been found that the welding current flowing in the electrode under some conditions sets up a magnetic field causing the arc to become wild. Slanting the electrode forward or backward has an effect on this condition. The path of the current in the work also occasionally causes this trouble. Generally speaking, one welds away from the ground connection but sometimes a change in the location of the ground connection will eliminate undesirable magnetic fields and the arc will become steady.

Steam or vapors will make an arc unstable and may cause it to go out frequently to the detriment of the weld. Such a condition might arise in sealing a crack in which some oil or water remains. As the metal is heated this matter turns to a vapor and rises through the crack into the arc.

## IMPURITIES

Some impurities affect a weld by weakening it, some by making it brittle and others by making the deposited metal so hard that it cannot be conveniently machined. Gas pockets, slag, oxides, etc., will materially weaken a weld and can be best eliminated by using a short welding arc and by keeping the weld and electrodes clean. Grease and dirt on the surface to be welded, or in the electrode, will result in gas pockets or slag inclusions and a long arc will result in oxidized or burnt metal.

Brittle and hard welds are often caused by a long arc which permits the hot metal to be exposed to the air with the consequent absorption of nitrogen which has been largely blamed for brittle welds. This is particularly true of welds on metal where the carbon content in either the electrode or the work is .30 per cent or more. Oxidized metal will also cause brittle welds. If oil and grease are not thoroughly cleaned off the surface to be welded, the residue, which is burned during the welding, will enter the weld and make it hard.

In welding with the carbon arc, hard welds may be caused by too short an arc causing carbon to be carried into the weld.

The weld should be kept clean at all times. Before beginning a weld the work should be thoroughly cleaned along the joint by means of a steel wire scratch brush or sand blast to remove scale, and grease should be removed by washing with gasoline and alkalies or a sand blast may be used. As the weld progresses, the metal adjacent to the point at which the arc stopped should be cleaned each time an electrode is changed. This can be done with a scratch brush. (See Fig. 14.)

Porosity is caused by the inclusion of gas forming material in the weld, such as dirt; by poor electrodes or poor metal in the work; by excessive heat causing the molten metal to boil; or by not properly welding over the joint where the arc is stopped. (See page 28, Fig. 22.)

## ELECTRODES

### Metal Electrode

In general, the metallic electrode for welding the commercial grades of wrought iron plate, structural and cast steel, and to a considerable extent of cast iron, should be a high grade of low carbon steel wire which has a carbon content of .20 per cent or less. Practically all commercial electric welding wire on the market meets this requirement, although there are a number of special electrodes containing greater amounts of carbon which are used for special purposes. The medium and high carbon steel electrodes are used where a hard deposit is required, but are not generally satisfactory where strength is necessary. In ordering, "Electric Welding Wire" should be specified since wire for acetylene welding is often treated in such a way as to render it unsuitable for electric welding.

The electrode wire should be cut into pieces convenient for the operation. A length of 14 to 18 in. is satisfactory since it is about the greatest length an operator can handle; at the same time it reduces the number of times the electrode is changed, and consequently the wastage.

With an electrode which is red hot, it is impossible either to start an arc or to maintain it. The exact temperature varies with different electrodes but in general it is advisable to keep the electrode cool. The passage of the welding current and the heat conducted back from the tip tend to heat that portion of the electrode wire carrying current. Accordingly when the welding current is high for the electrode size, the wire should be gripped in the middle. By this means the portion carrying current is all consumed before it has time to become too hot for use. With lower current values, the electrode is gripped by the end to save time and to minimize the number of times the arc is interrupted.

**Welding Currents (Bare Metallic Electrode)**

It is difficult to give universally applicable figures covering current, speed, etc., for electric arc welding due to the effect of conditions under which the work is done, the character of the work, and to a very large extent the skill of the operator. The following figures are based on favorable work conditions and a skilled operator. However, they are approximations only and are given merely as a general guide.

Light work—25 to 125 amperes
Heavy work—up to 250 amperes

| Electrode Diameter in Inches | Amperes Hand Welding | Corresponding Plate Thickness in Inches |
|---|---|---|
| 1/16 | 50– 75 | Up to 3/16 |
| 3/32 | 60–100 | Up to 1/4 |
| 1/8 | 80–150 | 1/8 up |
| 5/32 | 125–200 | 1/4 up |
| 3/16 | 175–225 | 3/8 up |
| 1/4 | 200–250 | 3/8 up |

The same size electrode may be used with various thicknesses of plate. The heavier plate will require the use of the heavier currents.

The electrode wire should be uniform throughout its length in composition and hardness since these factors affect the melting point and the way the electrode will act in the arc. Occasionally electrodes will be found that are not uniform as evidenced by the fact that at intervals the arc will suddenly become wild and erratic and the metal may pass from it in large drops without any apparent change in the electrical conditions or in the manipulation of the electrode by the welder. It is probable that at points in the weld where this action has taken place there will be weak spots with poor penetration and such an electrode should not be used and metal deposited under these conditions should be chipped out before proceeding with the weld if a strong weld is desired. Electrodes containing a considerable amount of carbon are generally erratic in this way.

**Rate of Deposition (Bare Metallic Electrode)**

The electrode wire as used by the welder is separated into three portions which are disposed of as follows:

| | |
|---|---|
| **Metal usefully deposited** | This is deposited in the weld where desired. |
| **Metal lost** | This is dissipated as small particles that fall outside the weld and a small amount entirely unaccounted for. |
| **Discard** | This is principally the short ends of electrodes but a few electrodes will be included that are unsuitable for welding. |

The proportion of these divisions is approximately as follows although this varies with local conditions.

| | Spraragen[*] % | Knox[†] % | Average % | Automatic |
|---|---|---|---|---|
| Metal usefully deposited | 70.5 | 77.5 | 74 | 90 |
| Metal lost | 13.0 | 7.5 | 10 | 10 |
| Discards | 16.5 | 15.0 | 16 | |
| Total electrode supplied | 100 | 100 | 100 | 100 |

### Approximate Rate of Deposition, Lb. Per Hour

| Electrode (bare) | Amperes Current | Hand | Automatic |
|---|---|---|---|
| 1/16 | 75 to 100 | ¾ | 1½ |
| 3/32 | 100 to 150 | 1 | 2 |
| 1/8 | 125 to 175 | 1½ | 2½ |
| 5/32 | 150 to 200 | 1¾ | 3 |
| 3/16 | 175 to 300 | 2½ | 5 |
| 1/4 | 225 to 325 | 3 | 6 |

### Rate of Travel (Bare Metallic Electrode)

| Thickness of Plate in Inches | [‡]FEET PER HOUR (BUTT WELD) | | |
|---|---|---|---|
| | Hand Welding | Semi-Automatic Welding | Full Automatic Welding |
| 1/16 | [§] | 25 to 50 | 100 to 200 |
| 3/32 | 10 | 20 to 40 | 75 to 150 |
| 1/8 | 7½ | 15 to 30 | 40 to 75 |
| 3/16 | 6¼ | 12 to 24 | 25 to 50 |
| ¼ | 5 | 8 to 16 | 15 to 40 |
| ⅜ | 2½ | 5 to 10 | 10 to 20 |
| ½ | 2 | 2½ to 5 | 5 to 15 |
| ¾ | 1¼ | 1¾ to 3½ | 3 to 6 |

These figures are actual welding speeds and will be modified on production work by idle time, preparation, etc.

### Special Electrodes

Phosphor bronze electrodes are generally used for welding copper, brass and bronze and sometimes it is necessary to reverse the polarity and make the electrode positive.

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[*] William Spraragen is secretary of the American Bureau of Welding. At the time these results were obtained, Mr. Spraragen was engaged in research work for the Welding Research Sub-Committee of the Emergency Fleet Corporation.

[†] H. G. Knox, formerly commander, U. S. Navy. At the time these results were obtained Commander Knox was the representative of the U.S. Navy on the Welding Research Sub-Committee of the Emergency Fleet Corporation.

[‡] To reduce to "inches per minute," divide by 5.

[§] Not usually practical for hand welding on a production basis.

### Carbon and Graphite Electrodes

These electrodes should be rods of hard, homogeneous uncored and uncoated carbon or graphite. They need not be chemically pure, but should not have any considerable amounts of foreign material content in the carbon. The carbon electrode is somewhat stronger than graphite and, therefore, will stand handling with less breakage. Either type will break if subjected to blows, either by hitting against objects or by dropping on the floor. The burning away of these electrodes is caused by the electrode being exposed to the air while very hot. This heat is largely caused by the resistance of the material and as graphite has a lower resistance, it will carry greater current for the same heating, or it can be used for the same currents as a carbon electrode, but with much slower rate of burning away.

### Welding Currents (Carbon and Graphite Electrodes)

The maximum values of current ordinarily used with these electrodes are as follows:

| Diameter of Electrode in Inches | Maximum Amperes Graphite | Maximum Amperes Carbon |
|---|---|---|
| ¼ | 100 | 75 |
| ½ | 300 | 200 |
| ¾ | 500 | 400 |
| 1 | 1000 | 600 |

Lower currents than the above may be used, but higher values will result in undue burning away of the electrode. The length of electrode depends on the particular class of work to be done. Long carbons reduce the percentage of short ends thrown away, but are more liable to breakage. The average lengths range from 6 to 12 in.

### Cutting Speeds (Carbon and Graphite Electrodes)

For cutting steel plate the following curves give the approximate speed to be expected.

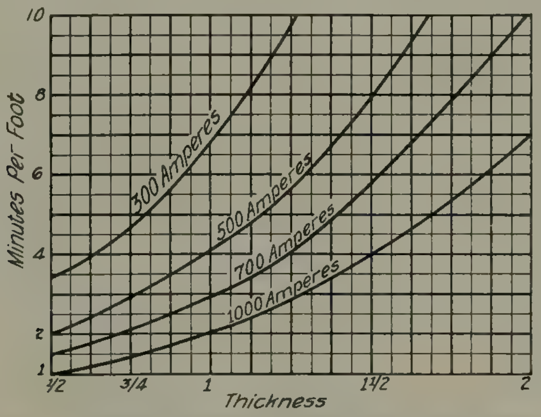


Fig. 5. CURVES SHOWING CUTTING SPEED FOR SHEET STEEL USING THE ELECTRIC ARC WITH CARBON ELECTRODES

### Rate of Deposition (Carbon and Graphite Electrodes)

For depositing or building up metal by means of the carbon arc on flat surfaces where the work is accessible and all conditions favorable, the following figures may be used:

| Current Amperes | Pounds Per Hour | Cubic Inches Per Hour |
|---|---|---|
| 200 | 1½ | 5.4 |
| 300 | 3 | 10.8 |
| 400 | 4½ | 16.2 |
| 500 | 6 | 21.6 |

For continuous work the above figures may be used, but for short jobs of ten minutes or less the rate of deposition may be doubled.

In the following pages reference is made to "carbon" electrode but the remarks apply as well to graphite.

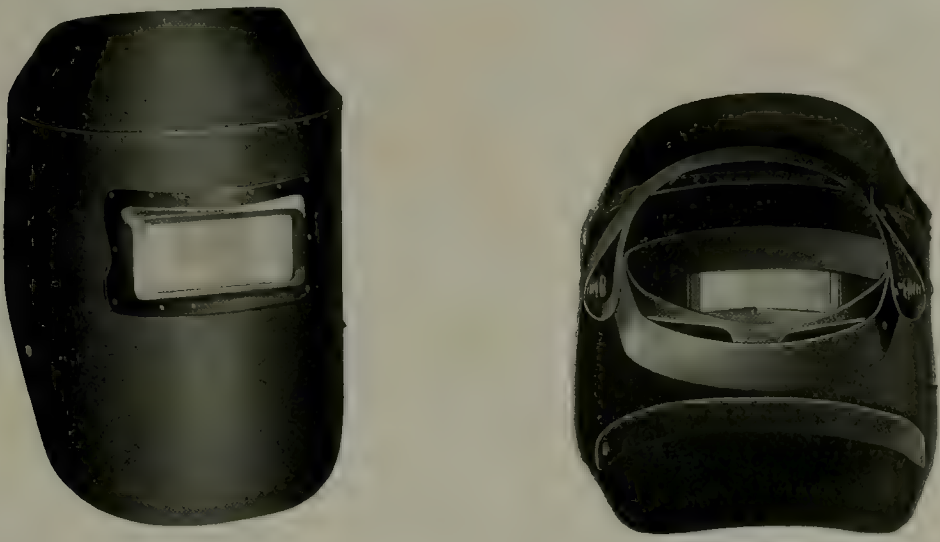
### Filler Metal

The metallic electrode ordinarily provides its own filler metal by being carried over and deposited on the piece being welded. In some special cases it is possible to use the heat of the metallic arc to fuse off additional metal from a filler rod, but it is difficult to fuse all this metal together properly and this should only be attempted by an expert. Very little is gained in the matter of speed. When the carbon electrode is used, any metal added must come from a filler rod or other metal introduced into the arc and melted down by it. The soundness of the weld depends on having a molten spot on the work into which the molten filler metal is deposited and thoroughly mixed by the circulation due to the heat of the arc. The metal used as filler will depend on the work to be done and quality of the metal being welded. For steel plates or castings the filler metal is ordinarily the same as used for metallic electrodes, although, for, carbon welding, rods of ⅜ to ¾ in. in diameter are usually employed. In filling large openings it is sometimes possible to use metal chips, steel turnings, or small pieces of steel, but where irregular shaped material is used, care should be taken to see that the added metal is thoroughly fused and not merely a plastered-over shell of apparently sound metal. For cast iron the filler metal may be either cast iron rods especially made for this purpose and containing considerable silicon, or in some cases it is possible to use small pieces of ordinary cast iron, but the precautions outlined above should be observed.

## ACCESSORIES

### Helmet and Hand Shield

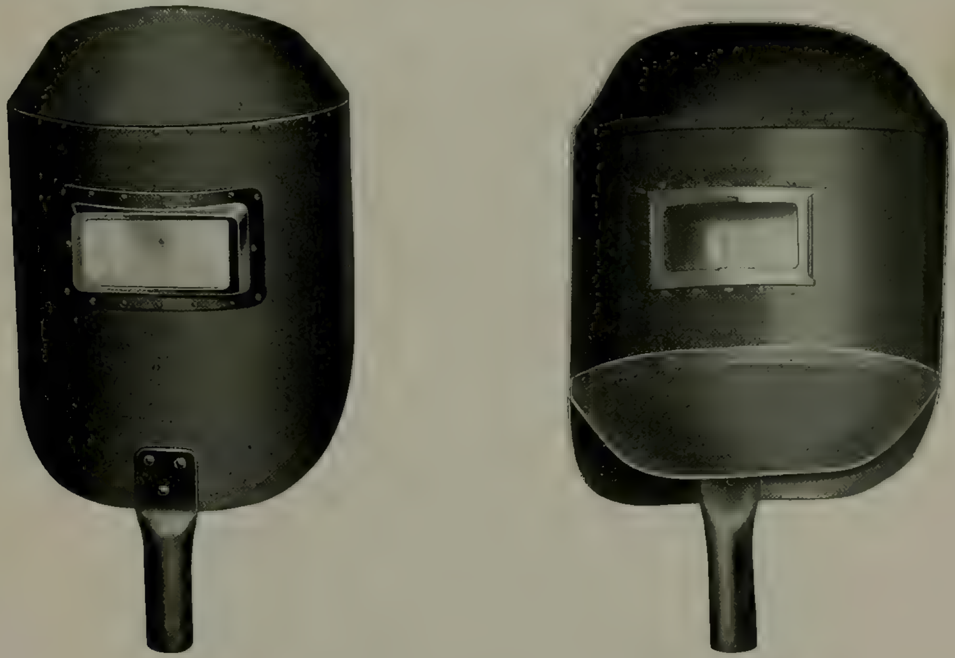
The helmet is a shield to protect the operator's face and neck from the direct light from the arc. It is preferably constructed of some insulating material, and provided with a window of protective glass through which the operator views the welding arc. It is designed to be supported from the operator's head, leaving both hands free, and generally is arranged so it can be tilted up on its support out of the way without entirely removing it from the operator's head. It should prevent entrance of light from the side or rear caused by other welders. The color should be dark so as to reflect practically no light. (See Fig. 6.)



**Front View** **Rear View**

Fig. 6. HELMET FOR OPERATOR

The hand shield is similar to the helmet except that it is provided with a handle instead of a head support. It is held in one hand by the operator who manipulates the electrode holder with the other hand. (See Fig. 7.)



**Front View** **Rear View**

Fig. 7. HAND SHIELD FOR OPERATOR

The material in the arc is at a very high temperature so that the light given out is intensely brilliant and contains a large proportion of ultra violet radiation. This type of radiation is chemically active and will cause painful though not necessarily permanent injury to the eyes or the skin. These radiations should be eliminated by the welder's glass used in the helmet and hand shield which should also bring the intensity of the visible light down to a point where the glare will not injure the eyes. Some glasses seem to act properly but allow a part of the invisible ultra violet light to pass, causing considerable eye injury to the operator. Glasses should either be tested by a spectroscope for this quality or should be purchased from a company known to deal only in reputable material.

Each piece of glass in the helmets and hand shields which are used in the welding department of the General Electric Company is subjected to a comparison, by means of a spectroscope, with a standard 100 per cent perfect glass. This test consists of a comparison of the ranges of light transmission by means of a visible spectrum. If the glass under test is found to transmit any harmful rays, it is rejected.

Good glasses are expensive when considered as glass, but if taken care of they will last indefinitely. The special protective glass should be provided with clear cover glasses, especially on the outside, which act as shields against the particles of molten metal thrown off from the arc. When the cover glasses become badly pitted by this material, they should be replaced, but this is relatively inexpensive material. The protective glass will last until it is broken by rough handling. **The arc should never be observed without suitable protection for the eyes.**

No chinks or holes in the helmet or hand shield should be permitted since only a brief exposure of the eyes to the direct rays of the arc is required to bring painful results. Painful and more or less serious injury to the eyes will result from carelessness in this respect.

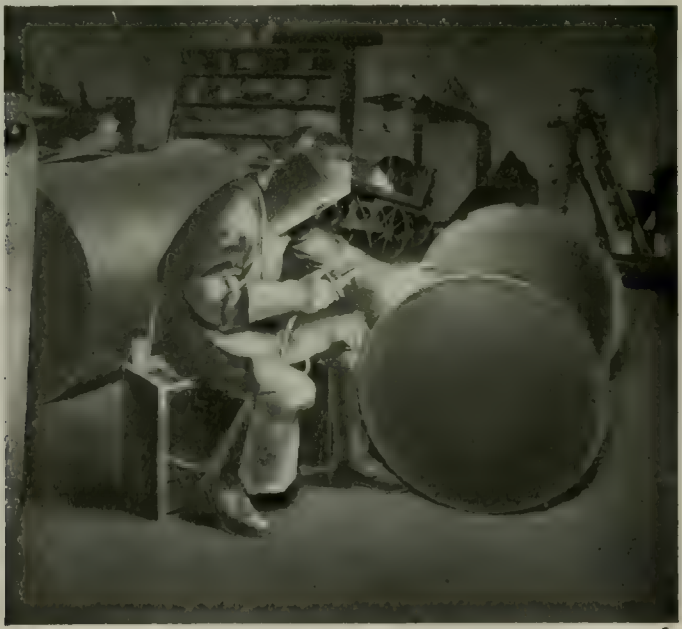


Fig. 8. PROTECTIVE EQUIPMENT FOR WELDER

### Clothing

A continual shower of sparks and globules of molten metal is thrown out by the welding arc. An apron of asbestos cloth or of leather will afford considerable protection to the welder's clothes, particularly in cases where the welder is sitting down while at work. (See Fig. 8.)

### Gloves

The skin of the hands in many cases does not seem to be very sensitive to the radiations from the arc and a great many welders prefer not to use gloves due to the greater freedom of the hands. Other operators prefer the gloves for the protection they afford. This is largely a matter of personal choice on the part of the welder, but in case gloves are used, they should be of leather and should be as flexible as possible without being so thin that they burn through easily. Gloves of inflammable material should never be used. The arms, neck, and face, however, should be covered since exposure of these parts will probably result in burns similar to sunburn, which though painful are not serious.

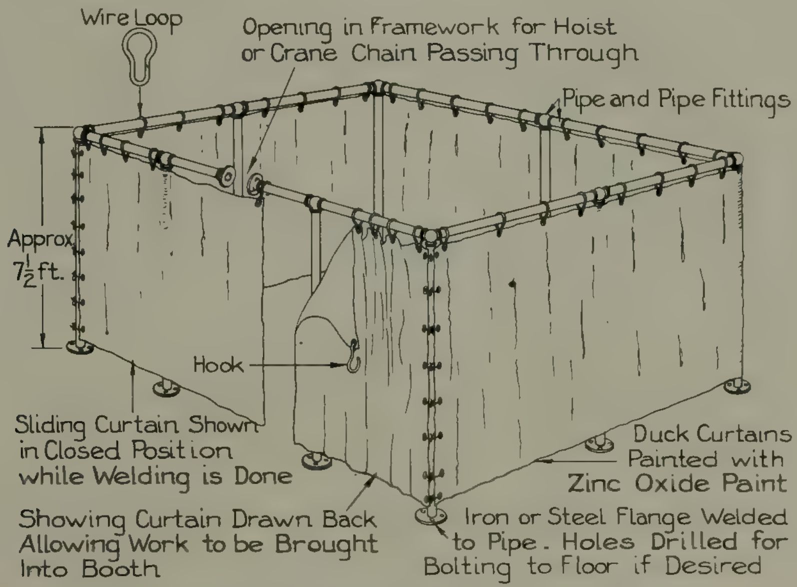

Wire Loop
Opening in Framework for Hoist or Crane Chain Passing Through
Pipe and Pipe Fittings
Approx 7½ ft.
Hook
Sliding Curtain Shown in Closed Position while Welding is Done
Duck Curtains Painted with Zinc Oxide Paint
Showing Curtain Drawn Back Allowing Work to be Brought Into Booth
Iron or Steel Flange Welded to Pipe. Holes Drilled for Bolting to Floor if Desired

Fig. 9. WELDING BOOTH FOR PROTECTION OF OTHER WORKMEN

### Screens and Shields

When welding is to be done in a shop where others are working, screens should be provided to protect the eyes of the other workmen from the arc. These screens may also be used to protect the arc from drafts of air which interfere with its stability. Where small work is being done, it is desirable to use a permanent construction in the form of booths or enclosures, one for each welder, but in the case of large work the screens may be portable. The material of these screens is ordinary canvas supported on any desired form and painted to make it opaque and also to provide a surface on which the particles of hot metal will not catch. A good surface paint for this service is a zinc oxide paint which has the property of not reflecting any ultra violet light, but this paint should be toned down with lampblack or other material to a bluish gray in order to reduce the reflection of visible light. (See Fig. 9.)

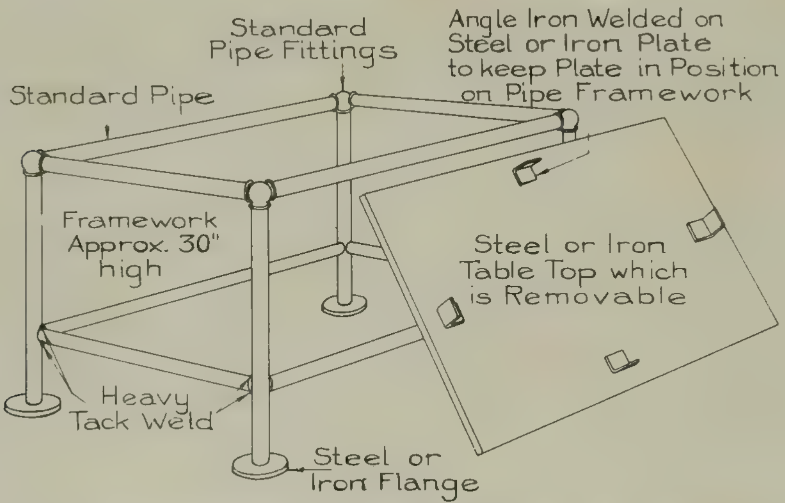

Standard Pipe Fittings
Angle Iron Welded on Steel or Iron Plate to keep Plate in Position on Pipe Framework
Standard Pipe
Framework Approx. 30" high
Steel or Iron Table Top which is Removable
Heavy Tack Weld
Steel or Iron Flange

Fig. 10. DIAGRAM SHOWING THE CONSTRUCTION OF A TYPE OF WELDING TABLE WITH REMOVABLE TOP

## Welding Table

For small work which may be picked up and moved about by hand, a welding table may be built of pipe fittings with a steel plate top to which the positive lead is connected. The work may be set on this bench, the contact being sufficient to carry the current. In many cases a vise mounted on the table will be found desirable. If the work is too large for the table, it may be set beside the table and a bar laid across to it. This will provide sufficient current carrying capacity, provided scale and rust do not entirely prevent contact.

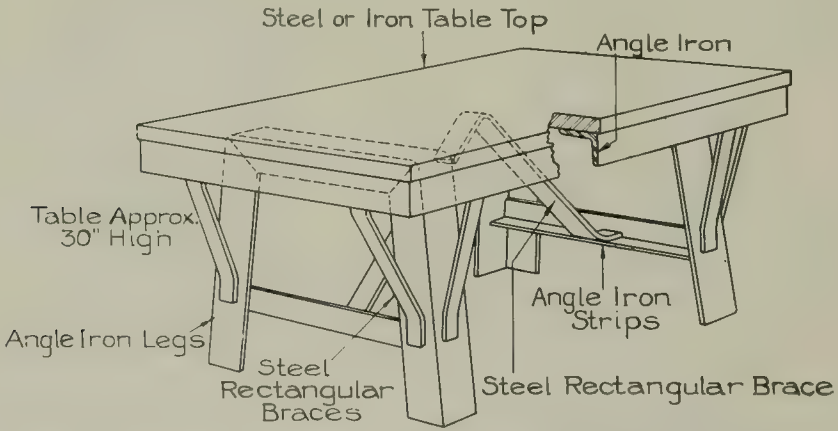


Fig. 11. DESIGN OF A WELDING TABLE CONSTRUCTED WITH STRUCTURAL STEEL PARTS ARC WELDED

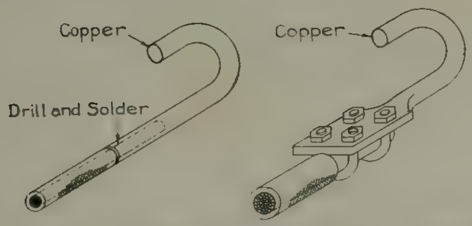


Fig. 12. ILLUSTRATION OF TYPES OF HOOKS FOR EASY ATTACHMENT OF GROUND LEAD TO WORK

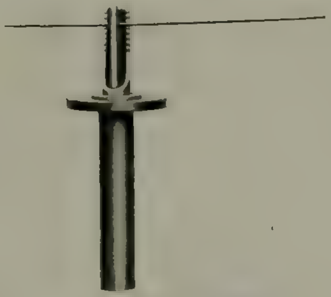


Fig. 13. A SUITABLE TYPE OF ELECTRODE HOLDER

### Ground Connection

For welding on large work a convenient terminal for the positive cable consists of a copper hook of proper size to which the cable is bolted. (See Fig. 12.) The terminal may be laid on the work or hooked on a projecting part. It is seldom necessary to actually clamp the return lead to the work unless the metal is thickly covered with scale or dirt which acts as insulation, in which case it is easier to chip or brush off a clean place for the contact than to use a clamp, for which a place should also be cleaned. Care should be taken to see that good contact is obtained. "The work" is an expression generally used to denote the piece or pieces of metal on which welding is being done.

The rails in a round house or car shop, if bonded, are usually connected to the positive lead and any car on these tracks may be welded by running only the cable leading to the electrode, the return cable being unnecessary since the current will be carried back through the rails.

### Electrode Holder

The function of the electrode holder is to electrically connect the electrode to the cable leading from the welding circuit and to provide convenient means by which the welder can hold and direct the electrode. The electrode holder furnishes a means of easily changing electrodes and should be such as to hold the electrode securely while the welding is going on. A fiber shield is usually attached to prevent heat radiation from the work piece from burning the fingers of the operator. All current carrying parts of the holder are insulated and the weight should be as low as possible to allow of easy manipulation. Mechanical strength is necessary to insure uniform deposition of metal and avoid interruptions. (See Fig. 13.)

### Welding Cable

A great deal depends on the operator's control of the arc. A section of extra flexible cable, at least 15 ft. long, connected to the electrode holder permits greater ease in the movement and control, and accordingly assists greatly in producing a high grade of work. The cable used by the General Electric Company has been adopted because of its general durability. This cable gives the maximum flexibility and possesses sufficient current carrying capacity for the service to which it is subjected. The cable is rubber covered with a tough braid imbedded in the rubber. This covering is durable and will safely stand rough usage.

On account of the intermittent nature of welding it is possible to use smaller cable for such circuits than is standard for the current capacities. By the use of smaller cables there is also a gain in flexibility.

The ground or return cable need not be as flexible as the electrode lead but should be flexible enough for convenient handling.

The carbon or graphite electrode welding arc is not as unstable as the metallic arc and therefore the manipulation of the electrode is not so important. For this reason the standard extra flexible dynamo cable built of strands of No. 24 or 25 copper wire may be used for connection to the electrode holder as well as for the return circuit.

The following sizes are in general use:

| Circuit | Welding Service | No. of Strands | Size of Wire Cable Strand | Insulation |
|---|---|---|---|---|
| Electrode holder connection | Metallic electrode up to 200 amp. | 37 | 35–0.007 | Rubber with braid imbedded in rubber |
| Electrode cable extension and ground or return cable | Metallic electrode up to 200 amp. | 225 | No. 24 | V.C. insulation for low voltage double treated cotton braid |
| Electrode cable and ground or return cable | Carbon or graphite up to 500 amp. | 375 | No. 24 | V.C. insulation for low voltage double treated cotton braid |
| Electrode cable and ground or return cable | Carbon or graphite up to 1000 amp. | 650 | No. 24 | V.C. insulation for low voltage double treated cotton braid |

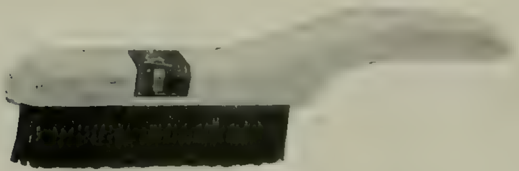


Fig. 14. A TYPE OF STEEL BRUSH COMMONLY USED

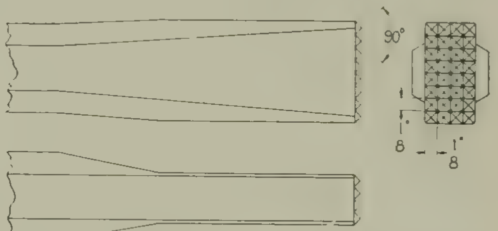


Fig. 15. ROUGHING TOOL FOR REMOVING SCALE AND SLAG FROM WELDS

### Accessories for Cleaning

Cleanliness of the metal adjacent to and forming the weld is of the greatest importance. Accordingly, the following suggestions are offered:

STEEL WIRE SCRATCH BRUSH. This may be used for light rust and scale and for cleaning between layers in heavy welds. (Shown in Fig. 14.)

CHISEL—HAND OR AIR. This should be used for removing heavy scale, slag from covered electrodes, or scale from oxyacetylene cuts, etc. The use of a roughing tool, or a chisel having a cutting face as shown in Fig. 15, is recommended by many for removing the scale. Great care should be taken to see that fragments of scale are not driven down into the metal by this tool. This frequently occurs and porous spots in the weld result.

SAND BLAST. This may be used for rust and scale, grease and dirt of all kinds.

GASOLINE. This may be used for removing grease or oil from machine parts. The metal near the weld should be well dried and the gasoline removed either by wiping or by the use of heat since the vapors given off interfere with the steadiness of the arc. Lye (caustic soda) may be also used as a cleaner. Pickling may be used for small parts.

### Backing Material

Carbon blocks may be used to prevent molten metal falling through when a weld is made from only one side. The metal will not adhere to carbon and a smooth appearance can thus be obtained. The metal next to the block will absorb a small amount of carbon and consequently will be harder than the rest of the material. The arc should never strike the carbon directly or this effect will be greatly increased. This should be considered if the surface is to be later machined. In building up pads, carbon blocks may be used as dams to keep the molten metal in place. Carbon sticks may be used to keep a hole open through a weld.

Copper may also be used for dams and backing, but the arc should never be allowed to touch the copper, otherwise the weld will be contaminated by the material, or it will weld fast and will be very hard to remove after the weld is completed. If the arc is kept away from the copper and the molten metal allowed to flow down against the copper, it will not stick.

The welding of thin sheet metal is facilitated by clamping it to blocks of copper or steel with a copper insert. This serves the double purpose of holding the edges of the sheet in position and also it carries away the heat and prevents burning through the thin metal.

Fire brick, asbestos and similar materials may also be used for molds, dams, etc. Fire clay or carbon powder with sodium silicate as binder provides a convenient material for molding dams of special shape.

### Cooling

A supply of sand and asbestos paper is often useful. Some castings after welding should be cooled very slowly to relieve the strains due to the contraction of the metal. This is particularly true of complicated castings. The work may be placed in a box of dry sand and well covered with sand for from one to two days. In the case of large pieces it is often satisfactory to cover thoroughly with asbestos paper.

### Preheating Equipment

Many castings should be thoroughly preheated before a weld is started, and in some cases the weld should be made while the heat is still kept on the casting. Gas and oil burners are used for this purpose. In some cases it is desirable to enclose the casting in a temporary oven of ordinary brick, built without cement, in order to heat the whole casting uniformly and in such cases the flame from the burner should not be permitted to play directly on the casting. Coke and charcoal are also largely used.

### Miscellaneous Accessories

Particularly in shops where job welding is done, the variety of welds involved calls for the use of many tools and odds and ends of equipment. The few appliances listed below will suggest other possibilities.

Portable Drill.
Portable Grinder—to finish off surface of welds, to prepare joints for welding, to remove hard metal, etc.
Tongs of various kinds for handling hot pieces of metal.
Crane or Chain Block.
Wedges—used for lining up parts.
"C" Clamps—to hold parts in position.
Waste—soaked with water, this is often used to prevent the spreading of heat away from the weld.
Soapstone crayon—for marking on hot metal.

## CONCLUSION—PART I

In many cases the reader is desirous of becoming a welder and before going into details as to the procedure to be followed in making welds of various kinds and of various materials, he should be able to strike and hold a correct welding arc. He should also be able to make simple welds indicating complete control over the arc in any position, that is, with the plates lying either in flat, vertical or overhead positions.

Part II consists of a number of exercises, graded so that the operator can progress from the simpler to the more difficult and gradually acquire the necessary control of the arc since this is the fundamental requirement of welding and without it good welding cannot be expected.

Fig. 16. ARC WELDER AT WORK

# PART II

# TRAINING COURSE FOR OPERATORS

While learning to weld the beginner will find it convenient to use a bench or table with a steel plate top connected to the ground lead as described before. The advantages of this are:

1. The welder can sit in a comfortable position and by avoiding a strained position can better concentrate on the exercise.
2. The steel top will catch many of the sparks and prevent burning the floor or bench.
3. The exercise plates can be laid on the steel top which will make the connection to the ground circuit.
4. For vertical and overhead welding the plates can be attached to the bench top by short tack welds.

A screen should be placed around the table to protect the eyes of others.

It is recommended that the beginner use a hand shield during the exercises on metallic electrode welding since it keeps the left hand occupied and prevents using the left-hand as a brace for the right hand. Also the shield can be quickly moved before the face, allowing the operator to visibly direct the electrode, until the instant before it makes contact, and strikes the arc.

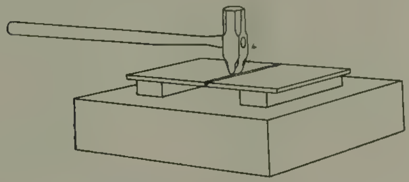


Fig. 17. METHOD OF TESTING A BUTT WELD WITH SLEDGE

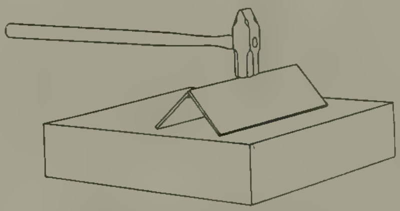


Fig. 18. METHOD OF TESTING AN ANGLE WELD WITH SLEDGE

### Materials Required

The materials required are as follows:

A source of welding current with suitable means of current adjustment, a hand shield, the necessary cables, and an electrode holder. (See Part I, pages 9, 17, and 21.)

1 welding table about 30 in. high with stool and screens.

1 12- to 16-lb. sledge with wedge head for breaking welds. (See Figs. 17 and 18.)

1 heavy iron or steel block, 1 ft. by 2 ft., 6 in. thick, used as an anvil for breaking welds. (See Figs. 17 and 18.)

2 small blocks of steel 3 in. by 3 in. by 1 ft. (See Fig. 17.)

1 bench vise attached to table.

1 machinist's hammer 1½ to 2 lbs.

Several cold chisels.

1 steel wire scratch brush. (See Fig. 14.)

Several pieces of copper ½ in. by 3 in. by 6 in.

A considerable stock, 50 or 75 pieces of sheet steel, about 4 in. by 12 in. by $\frac{3}{16}$ in. These may be pieces of scrap steel and for the first twelve exercises need not have smooth edges.

A supply of standard welding wire, ⅛ in. diameter cut to length of about 14 in. and reasonably straight; 50 lbs. is enough to start, as this material can be purchased as needed.

The beginner will profit greatly by watching, for a time, an experienced welder. He should closely observe the motions used in striking the arc and in moving along a weld. His ear will become accustomed to the sounds of the arc, both when it is too long and when it is of proper length. By using an electrode holder and electrode, but without any current, he can practice the motions of striking the arc. The hand shield should be used just as though an arc were to be struck, as the operator should make it a habit to always cover the eyes before striking the arc. Repeated "flashes" of the arc on the eyes, even though they are only momentary, will cause eyeburn.

### Position of the Welder

The welder should sit on a stool directly in front of the work and with his shoulders squarely parallel with the edge of the work table. His feet may rest on the floor, or a foot rail under the table, or on the rungs of the stool or wherever they will be comfortable. This position tends to prevent involuntary movement.

The electrode holder should be held in the right hand, just tightly enough to fully control its movements and not gripped so tightly that the muscles are cramped or bound in any degree. The elbow should be held away from the body, the whole arm being almost horizontal. This leaves the entire arm free to move from the shoulder down. (See Fig. 19.)

The cable to the electrode holder should be drawn over the welder's lap from the left side with just enough slack to allow free motion of the electrode holder. (See Fig. 19.) By supporting the cable in this way, the weight and drag of the cable is kept off the right hand. Some operators prefer to loop the cable over the right shoulder.

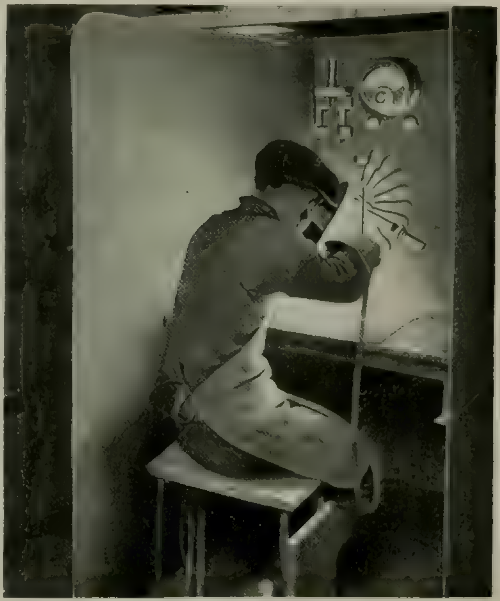


Fig. 19. POSITION OF WELDER WHEN WELDING SHOWING SHIELD, ELECTRODE, ELECTRODE LEAD, AND WORK TABLE

The left hand holds the hand shield, the elbow usually being braced against either the table or the welder's left knee to steady the body. (See Fig. 19.)

The operator should try to get in any easy position where the whole body is comfortable and braced so as to be steady without strain, leaving the right arm entirely free.

### Striking the Arc

The principal precaution to be observed in striking the arc is to prevent "freezing" or "sticking" the electrode to the work. This is caused in the following way. The electrode touches the work only on a small surface, a point or sharp corner. The heavy current melts this and it sticks to the plate. More of the electrode melts and as it is being pushed against the plate, the end of the electrode will weld fast. The current then rapidly heats the rest of the electrode unless it is broken away at once. This trouble is avoided by quickness in making the electrode touch the work and come back just away from the plate. The electrode should be drawn back to the arc length somewhat more slowly than the movement in the first part of the action. (See Fig. 20.) In the effort to prevent sticking, the beginner has a tendency to jerk the electrode away too rapidly and too far, thus "snapping out" the arc.

Insert an electrode wire in the holder, gripping it by the middle.

Adjust the current for about 125 amperes when welding. (Instructions accompanying the welding equipment will give directions for this step.) With an ammeter it is possible to set the current by holding the electrode holder against the plate and reading the current. This value will be roughly about one-third more than when the arc is being held. To obtain 125 amperes in the arc, the short circuit current will be about 160.

Lay one of the exercise plates flat on the table.

Take the welding position described before. (See Fig. 19.)

Holding the electrode vertical, bring it to the point on the plate where the weld is to be started but do not touch the plate until the hand shield is moved in front of the face.

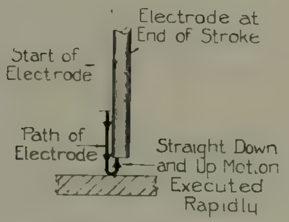

Electrode at End of Stroke
Start of Electrode
Path of Electrode
Straight Down and Up Motion Executed Rapidly

Fig. 20. STRIKING THE ARC

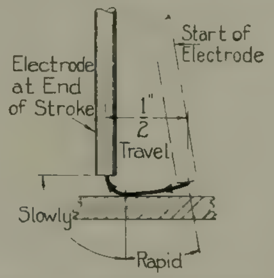


Fig. 21. STRIKING THE ARC

Touch the electrode very lightly and quickly to the work by a motion of the wrist. This is a quick picking action shown by Fig. 20. The movement in touching the plate and just freeing the electrode should be quick. Then more slowly bring the electrode away about $\frac{1}{8}$ in. or until the arc has the proper snapping sound. Hold the arc a few seconds and then snap it out. If the electrode sticks or freezes immediately, bend it from side to side with a steady pull which will probably free it. If this fails and the electrode becomes red hot, the circuit should be opened

By opening the line switch, or—
By freeing the electrode from the holder, or—
By lifting the plate from the bench.

On cooling, the electrode can be broken away with a hammer.

The welder should practice starting the arc in this way, holding the arc a little longer time at each attempt and moving it slowly over the plate until he is able to start and hold the arc consistently. Move the arc straight along and do not try to spread the bead or to weave or impart a zig-zag motion to the electrode holder.

A method of striking the arc to avoid "sticking" is shown in Fig. 21. In this method the action to a certain extent consists of scratching the electrode on the surface of the plate The withdrawal of the electrode should be slower than the rest of the motion.

### Depositing Metal

In advancing the arc, care should be taken not to move the electrode faster than is possible for the arc to melt a place on the plate for receiving the deposited metal. If the arc is moved too fast the metal will be merely laid on the plate with no penetration. (See Fig. 3.) The operator should keep the arc traveling forward just fast enough to keep it at the forward edge of the crater. (See Fig. 2.) This is the greatest speed of travel possible with the combination of plate thickness, electrode diameter and current used. Traveling the arc forward less rapidly will result in a bead somewhat higher and wider. Too slow a speed will result in overlap of the bead and possibly oxidized metal caused by the melting of a large crater and exposure of this hot metal to the air. The gases and vapors from the arc will to a certain extent protect the metal in a small crater.

These exercises should be continued until the operator is able to start the arc practically every time. Gradually increase the length of the bead and make curved lines, letters, etc., but do not weave.

Now begin to examine the beads deposited while moving the arc along the plate, by comparing them with Fig. 24. The sound of the arc, and the appearance both from the standpoint of length and size and also the size and number of sparks should be noted in connection with the appearance of a bead. Chip off the bead, commencing at the end where the weld was begun since this is usually the weakest point. Continue making beads 3 or 4 in. long until the bead has the appearance of a good weld, that is, even height, width, no overlap, good penetration. If a voltmeter is connected to measure the arc voltage, it will help to have someone watch this and advise from time to time what the voltage is. It should be kept from 18 to 20 and the appearance under these conditions noted.

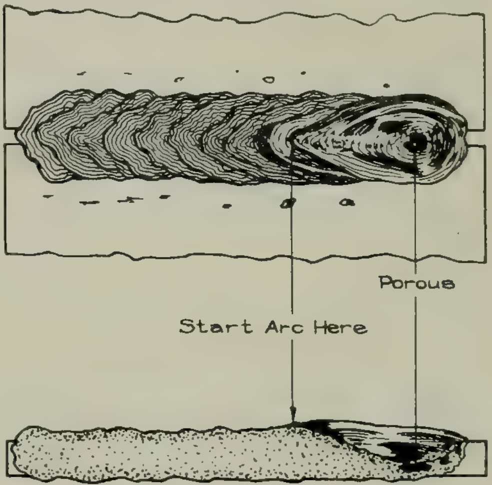


Fig. 22. SECTION OF DEPOSITED METAL SHOWING PENETRATION AND CRATER

Now repeat the above exercises, first using a current of 100 amperes in the arc and then of 75 or 80. These will require increasingly greater steadiness of the hand both in starting and in holding the arc after it is started. The observations above as to arc sound and appearance should be checked in each case against the appearance of the bead. The surface of the bead should consist of regularly spaced ripples with no holes or spongy places. No large drops of metal should be outside the weld on the plate and when the bead is chipped off, it should be necessary to cut it away the full width of the bead, thus showing that there is no overlap.

It will be noted that wherever the arc stops there is a spongy, porous spot in the crater. In the case of long welds where it is necessary to use more than one electrode, such a spot will be found wherever the arc is stopped to change electrodes. In recommencing such a weld, the arc should be started just at the rear of the crater and the weld carried across it. (See Fig. 22.)

It can now be assumed that the welder is able to start an arc and hold it uniformly for a short time. From this point on, the exercises will take the form of lessons with certain conditions specified and certain requirements which are to be met by the finished weld before the student should pass on to the next lesson.

If at any time the student feels a strain in his arm or shoulder, or the welds suddenly diminish in quality, he should rest for a half hour or so. A certain amount of rest is obtained reviewing the exercises covered by Lessons No. 1, 2, 3, and 4.

## GENERAL INSTRUCTIONS

In approaching each lesson the student should consciously divide the preparation into several distinct steps:

| STEPS TO BE PERFORMED | REASONS OR POINTS TO BE EMPHASIZED |
|---|---|
| 1. Place work plate on bench. | 1. Bench should be clean so work will be steady, and make good electrical contact with the ground lead. |

| | |
|---|---|
| 2. Clean metal where weld is to be made. | 2. See note on Impurities in Part I, page 12. |
| 3. Make ground connection. | 3. If necessary, the plate should be cleaned with a scratch brush or chisel to provide good electrical contact and avoid local heating and waste of power at this point. |
| 4. Put electrode in holder. | 4. Electrode may be gripped at the middle if the work requires very steady handling of the electrode. Holding the electrode by the end makes it unnecessary to stop the arc to change the electrode but makes it more difficult to hold the arc steady. |
| 5. Adjust the current. | 5. The value of current to be used for each exercise is given in the instructions. The method to be used in adjusting for current depends on the type of welding equipment and such instructions are usually supplied with the equipment. |
| 6. Strike the arc and make the weld. | 6. The details of this step will depend on the requirements of the problem. |

## DETAILED INSTRUCTIONS ON EXERCISES (METALLIC ARC)

### LESSON No. 1

### Inch per Inch

**Conditions**

| | |
|---|---|
| Position of plate | Horizontal |
| Type of bead | Straight bead, no oscillation. |
| Direction of travel | Forward—away from operator. |
| Current in arc | 75 amperes. |
| Position of electrode | Vertical—perpendicular to plate. |

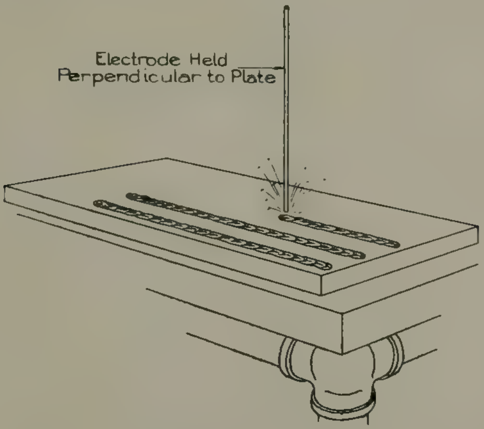


Fig. 23. THREE PARALLEL SINGLE BEADS

Fig. 24. THREE PARALLEL SPREAD BEADS

## LESSON No. 1—Cont'd

**Requirements**

Three straight continuous beads at least 6 in. long. (Figs. 23 and 24.) Do not let the arc go out while the bead is being run. Uniform width and height of bead. Proper penetration and no overlap. No signs of porosity. Length of bead should equal the length of electrode wire used. Maximum allowable difference between length of bead and of wire—¼ in. in 6 inches of length.

**Procedure**

It will help at first to draw a chalk mark on the plate, but before completing the lesson, the bead should be made without depending on a chalk mark to keep it straight. Take all the preliminary steps described before and strike the arc near the edge of the plate nearest the student. Slowly and steadily move the electrode across the plate away from the operator. keeping both arc length and rate of travel constant.

**Inspection and Test**

Examine and measure the bead and chip it off to see that it meets the requirements.

## LESSON No. 1-A

**Same as Lesson No. 1 Except—**

| | |
|---|---|
| Direction of travel | Toward operator. |
| Procedure | Same as Lesson No. 1 except start arc at far edge of plate and advance the arc toward the welder. |

## LESSON No. 1-B

**Same as Lesson No. 1 Except—**

| | |
|---|---|
| Direction of travel | Left to right. |

## LESSON No. 1-C

**Same as Lesson No. 1 Except—**

| | |
|---|---|
| Direction of travel | Right to left. |

Practice beads may be run on both sides of the plates used in these exercises.

RESULTS: From this lesson the student has become familiar with the handling of the electrode. He is able to hold a steady arc of proper length. He has an idea of the approximate length of weld obtainable with a given length of the electrode.

## LESSON No. 2

### Three Parallel Beads

**Conditions**

| | |
|---|---|
| Position of plate | Horizontal. |
| Type of bead | Flat spread bead. |
| Direction of travel | Forward. |
| Current of arc | 90 to 100 amperes. |
| Position of electrode | Vertical. |

**Requirements**

In this and all following lessons, the deposited metal should meet all the requirements of a good weld—uniformity of height and width, regularity of ripples, good penetration and no overlap, no signs of porosity.

These factors will not be mentioned again, but it should be understood that they are of the first importance and it is assumed that the student will make welds that meet these requirements.

The particular requirements of this lesson are: Three parallel beads each 10 in. long, $\frac{3}{8}$ in. wide and $\frac{1}{8}$ in. high, with a space $\frac{1}{2}$ in. wide between rows. (Fig 24.)

**Procedure**

The same as Lesson No. 1 except that in order to get the required width of bead, it will be necessary to spread the weld by weaving the electrode back and forth slowly across the line of travel. The arc will follow a path similar to that shown in Fig. 25.

This cross motion should not be too rapid or the weld will not penetrate and will be similar to that shown in Fig. 3(b). This movement of the electrode should be governed by the same conditions laid down in the preliminary instructions allowing for the different motion. Each time an electrode is changed, use the scratch brush to clean the surface where the bead is to be deposited and seal the crater properly. See Fig. 22.

In making this weld it will be necessary to use more than one electrode per bead. Where the arc is broken there will be found the condition described on page 28 and shown in Fig. 22.

Put a chalk mark on the plate opposite each point where the arc is stopped.

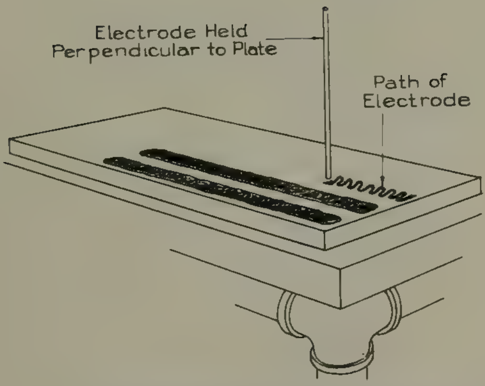


Fig. 25. DIAGRAM SHOWING ELECTRODE TRAVEL IN MAKING SPREAD BEAD

**Inspection and Test**

Examine and measure the beads to see that the requirements are met. Chip off a few of the practice beads to see that no porous spots are left and that the metal is securely welded at the points where electrodes are changed.

Make a few welds using the spread bead with the other directions of travel. Save the plates that were not passable for this lesson as they may be used for practice on later lessons.

## LESSON No. 3

### Three Parallel Beads in Two Layers

**Conditions**

Same as Lesson No. 2 except

Current in arc: 80 to 90 amperes. The reduction in current is due to the conduction of heat into the plate not being as rapid since the heat is applied to the top of a narrow ridge instead of the broad surface of the plate.

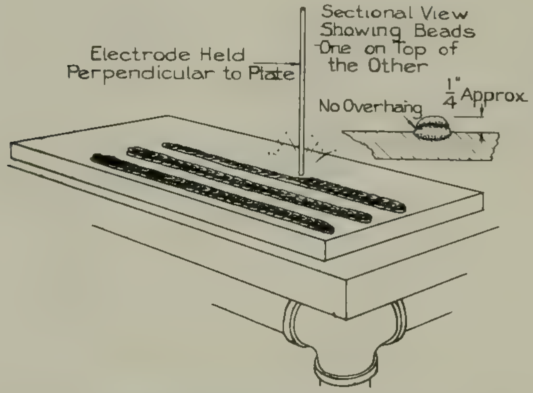


Fig. 26. DIAGRAM SHOWING CROSS SECTION OF THREE PARALLEL SPREAD BEADS IN TWO LAYERS

**Requirements**

A second layer deposited on each of the beads made in Lesson No. 2. Total height of completed beads, ¼ in.

**Procedure**

Use for practice the plates from Lesson No. 2 that were not passable.

Clean well the surface of the preceding beads with a scratch brush. When a good practice weld has been made, use the plate that passed the requirements of Lesson No. 2. Do not let the metal from the second layer run over the edges of the first layer. (Fig. 26.)

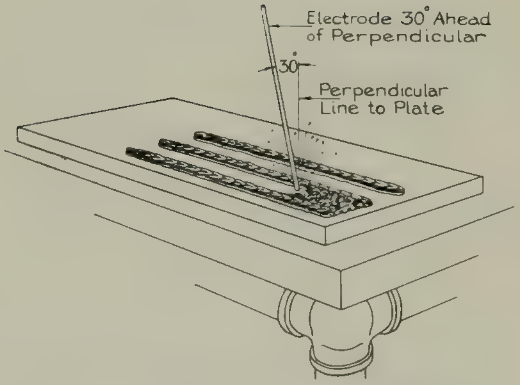


Fig. 27. METHOD OF FILLING IN BETWEEN BEADS MADE IN LESSON 3

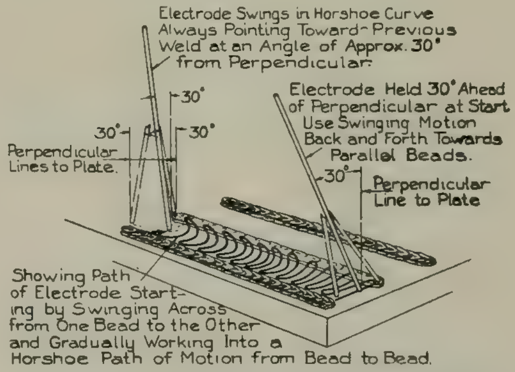

Electrode Swings in Horshoe Curve
Always Pointing Toward Previous
Weld at an Angle of Approx. 30°
from Perpendicular.
30°
30°
30°
Perpendicular
Lines to Plate.
Electrode Held 30° Ahead
of Perpendicular at Start
Use Swinging Motion
Back and Forth Towards
Parallel Beads.
30°
Perpendicular
Line to Plate
Showing Path
of Electrode Starting by Swinging Across
from One Bead to the Other
and Gradually Working Into a
Horshoe Path of Motion from Bead to Bead.

Fig. 28. DIAGRAM SHOWING PATH OF ELECTRODE WHILE FILLING IN BETWEEN BEADS OF LESSON 3

## LESSON No. 4

### Filling Space Between Welds Made in Lesson No. 3

**Conditions**

| | |
|---|---|
| Position of plate | Horizontal. |
| Type of bead | Flat spread bead. |
| Direction of travel | Forward |
| Current in arc | 125 to 140 amperes. |
| Position of electrode | Ahead 30 deg. from perpendicular to point the arc back into the weld. |

**Requirements**

Weld made in one layer. Same height as previous beads, leaving smooth surface. Weld must penetrate into plate below and into beads at either side to form a solid mass of metal.

**Procedure**

Clean the surfaces where the weld is to be made by means of the scratch brush and repeat each time an electrode is changed.

Similar to Lesson No. 3 except that in order to penetrate into the metal of the previous beads it will be necessary to direct the arc against the sides of the beads.

The electrode should be moved in the path shown in Figs. 27 and 28, forming a sort of horseshoe shaped path.

Examine the weld for appearance and chip off part of it to test for penetration.

## LESSON No. 5

### Inch per Inch

**Conditions**

| | |
|---|---|
| Position of plate | Inclined at angle of 45 deg. to table. Forward and upward away from operator. |
| Type of bead | Straight bead, may be slightly spread. |

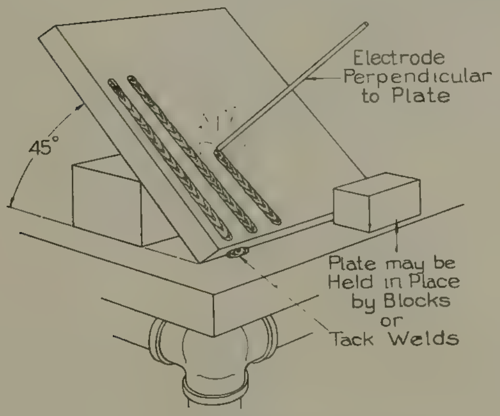


Fig. 29. LAYING THREE PARALLEL BEADS ON PLATE INCLINED AT 45° TO HORIZONTAL

### LESSON No. 5—Cont'd

**Conditions**

| | |
|---|---|
| Direction of travel | Upward on plate. |
| Current in arc | 75 amperes. |
| Position of electrode | Perpendicular to plate (Fig. 29). |

**Requirements**

Similar to Lesson No. 1.

**Procedure**

Similar to Lesson No. 1.

The plate may be rested against a brace or welded to the bench top by a weld about ½-in. long, just enough to support it. (See Fig. 29.) Begin weld near bottom of plate. The arc must be kept short or the metal will run causing uneven appearance.

## LESSON No. 6

### Three Parallel Beads

**Conditions**

| | |
|---|---|
| Position of plate | Same as Lesson No. 5. |
| Type of bead | Spread bead. |
| Direction of travel | Upward on plate. |
| Current in arc | 90 to 100 amperes. |
| Position of electrode | Perpendicular to plate. |

**Requirements**

Similar to Lesson No. 2 (see Fig. 24).

**Procedure**

Similar to Lesson No. 2 as modified by Lesson No. 5.

## LESSON No. 7

### Three Parallel Beads in Two Layers

**Conditions**

Same as Lesson No. 6 except

| | |
|---|---|
| Current in arc | 80 to 90 amperes. |

**Requirements**

Similar to Lesson No. 3.

**Procedure**

Similar to Lesson No. 3 as modified by Lesson No. 6.

Use practice plates from Lessons No. 2 and No. 6.

## LESSON No. 8

### Filling Space Between Welds Made in Lesson No. 7

**Conditions**

Same as Lesson No. 7 except

| | |
|---|---|
| Current in arc | 125 to 140 amperes. |
| Position of electrode | Ahead, 30 deg. from perpendicular to the plate, to point the arc back into the weld. |

**Requirements**

Similar to Lesson No. 4 (see Figs. 27 and 28).

**Procedure**

Similar to Lesson No. 4 as modified by Lesson No. 7.

## LESSON No. 9

### Inch per Inch

**Conditions**

| | |
|---|---|
| Position of plate | Vertical. |
| Type of bead | Straight bead, may be slightly spread. |
| Direction of travel | Vertical (upward). |
| Current in arc | 75 amperes. |
| Position of electrode | Horizontal—perpendicular to plate. |

**Requirements and Procedure**

Similar to Lesson No. 1.

The plate may be welded to the bench top by a short weld about ½ in. long. The necessity of a short arc is much greater in this lesson than in preceding ones and this will be appreciated by the welder on the first attempts. The only way to keep the metal where it belongs is by keeping the arc short.

## LESSON No. 10

### Three Parallel Beads

**Conditions**

| | |
|---|---|
| Position of plate | Vertical. |
| Type of bead | Spread bead. |
| Direction of travel | Vertical (upward). |
| Current in arc | 90 to 100 amperes. |
| Position of electrode | As in Lesson No. 9. |

**Requirements**

Similar to Lesson No. 2 (see Fig. 24).

**Procedure**

Similar to Lesson No. 2, as modified by Lesson No. 9.

## LESSON No. 11

### Three Parallel Beads in Two Layers

| | |
|---|---|
| **Conditions** | Same as Lesson No. 10 except |
| Current in arc | 80 to 90 amperes. |
| **Requirements** | Similar to Lesson No. 3. |
| **Procedure** | Similar to Lesson No. 3 as modified by Lesson No. 10. |

Use practice plate from Lessons No. 2, No. 6 and No. 10.

## LESSON No. 12

### Filling Space Between Welds Made in Lesson No. 11

| | |
|---|---|
| **Conditions** | Same as Lesson No. 11 except |
| Current in arc | 125 to 140 amperes. |
| Position of electrode | Ahead 30 deg. from perpendicular to point the arc back into the weld. |
| **Requirements** | Similar to Lesson No. 4 (see Figs. 27 and 28). |
| **Procedure** | Similar to Lesson No. 4, as modified by Lesson No. 11. |

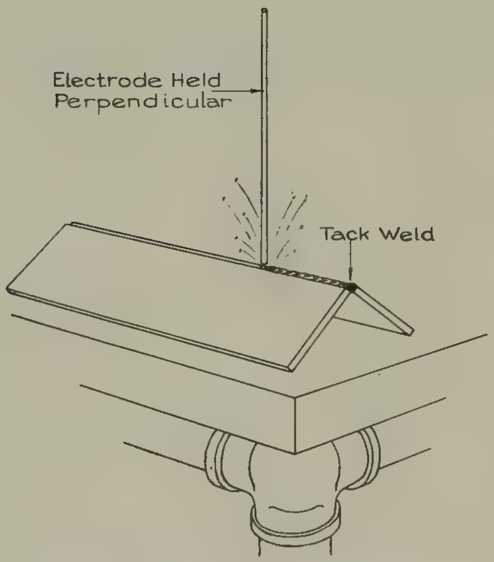


Fig. 30. METHOD OF MAKING RIGHT ANGLE BUTT WELD IN HORIZONTAL POSITION

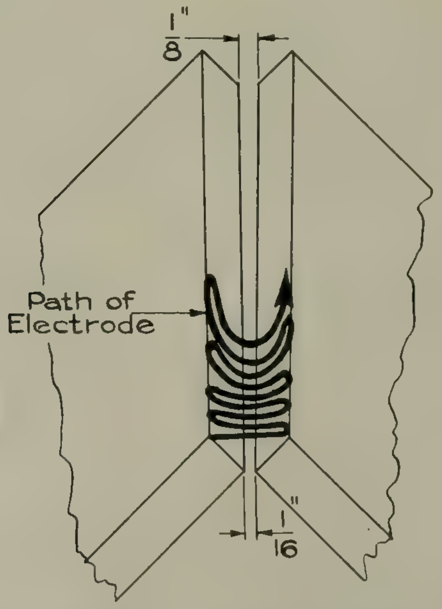


Fig. 31. PATH OF ELECTRODE IN MAKING RIGHT ANGLE BUTT WELD IN HORIZONTAL POSITION

The following results are obtained from Lessons No. 1 to No. 12 inclusive:

In the preceding lessons the student has learned to hold a proper arc and to deposit sound metal on plates in various positions. If heavier plates are available, it might be advisable at this time to try one or two of the lessons on plates of $\frac{1}{2}$ to $\frac{3}{4}$ in. in thickness. Use electrodes $\frac{5}{32}$ or $\frac{3}{16}$ in. in diameter and current corresponding.

These lessons have been preliminary to a certain extent although the welds made in Lessons Nos. 3, 4, 7, 8, 11 and 12 are used considerably in building up pads, etc. The following lessons deal more directly with actual welding operations.

## LESSON No. 13

### Butt Weld—Plates at Right Angles

**Conditions**

| | |
|---|---|
| Plates | Two pieces, $\frac{3}{16}$ in. thick by at least 8 in. long with one straight edge on each. Edges square as left by mill or by shear. **Do not bevel.** |
| Position of plates | See Fig. 30. |
| Position of weld | Flat. |
| Type of joint | Butt weld. |
| Direction of travel | Forward. |
| Current in arc | 110 amperes. |
| Position of electrode | Perpendicular to weld. |

**Requirements**

Good appearing weld, even across the top without bumps, craters, or dribbles over the edges. Weld must extend through bottom of groove and show on under side. The break should in general follow the middle of the weld. The grain of the metal should be uniformly fine and of a dull gray color.

**Procedure**

Place the plates as shown in Figs. 30 and 31 and with an opening of $\frac{1}{16}$ in. at one end, and $\frac{1}{8}$ in. at the other. Tack the end with the $\frac{1}{16}$ in. gap or opening. Start the arc at this end and as the weld advances, the shrinking of the deposited metal will gradually draw the plates together. Therefore, when the arc reaches any point along the weld, the plates at that point will be about $\frac{1}{16}$ in. apart.

At the beginning the path of the electrode will be a simple spreading motion to distribute the heat evenly. As the plates get hot the metal in the weld and at the bottom of the groove tends to fall or sag through. To prevent this the amount of heat in the middle of the weld is reduced by moving the electrode further up along the edge of the plates and making a more pronounced horseshoe shaped path, the sides of the horseshoe being about $\frac{3}{16}$ in. long. The travel across the middle of the weld should be made faster and that along the sides of the horseshoe slower. In this way the maximum heating is caused along the edges of the cold plate where good fusion is necessary. (See Fig. 31.) Do not run over the edges of the plates.

## LESSON No. 13—Cont'd

### Inspection and Test

When completed, allow the weld to cool. After examination, break it with the sledge as shown in Fig. 18. Pay particular attention to the points where the arc was restarted after changing electrodes. (See comments in Lesson No. 2.) If the break follows the edge of one of the plates and particularly if a fairly smooth black or bluish surface is found, it indicates that the deposited metal did not penetrate the metal of the plate at that point. The arc evidently was not carried up on the edge of the plate, and deposited metal merely ran down over this portion. A long arc might cause a similar appearance.

Bright spots in the weld indicate gas pockets and dark spots indicate slag or oxide inclusions. The motion of the electrode was too rapid and these foreign materials did not have time to rise to the surface.

## LESSON No. 14

This is the same as Lesson No. 13 except that, after tacking the plates as shown in Fig. 30, they are placed so the weld makes an angle of 45 deg. with the horizontal. The end having $\frac{1}{8}$ in. opening should be at the top. Begin at the lower end and weld upward and away from the operator. (See Fig. 32.)

Inspect, break and examine the weld.

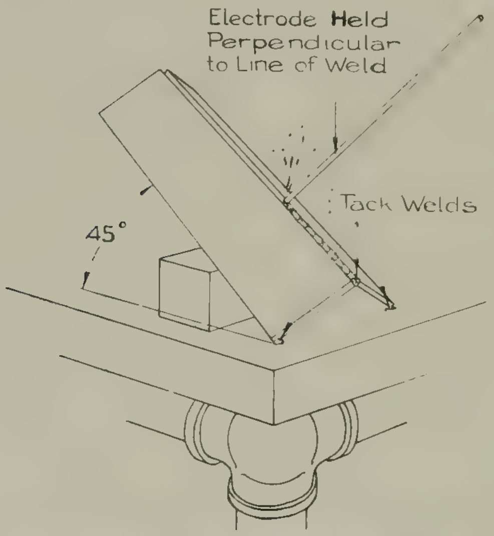


Fig. 32. METHOD OF MAKING RIGHT ANGLE BUTT WELD INCLINED 45° TO HORIZONTAL

## LESSON No. 15

This is the same as Lesson No. 14 except the weld is to be vertical. Begin at the bottom where opening is $\frac{1}{16}$ in. and weld upward.

Inspect, break and examine the weld.

The student will have noted the method used in allowing for contraction of the hot metal by spacing the plates so that the distance between them is less at the beginning of the weld than it is at the end where the weld finishes.

Several welds should be made in each of these lessons. It is often desirable to go back and repeat Lessons Nos. 1, 2, 3, and 4, for a few minutes to keep the hand trained and to a certain extent to rest it.

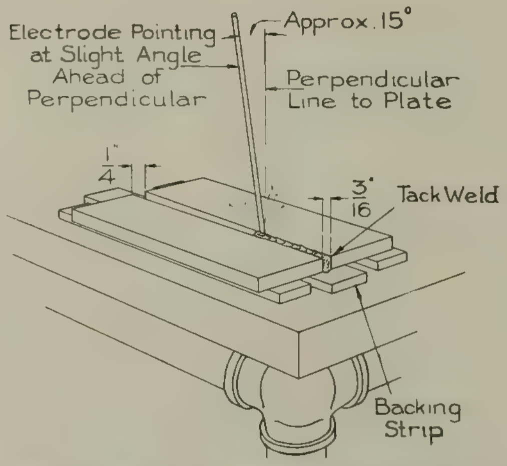

Electrode Pointing at Slight Angle Ahead of Perpendicular
Approx. 15°
Perpendicular Line to Plate
1"/4
3"/16
Tack Weld
Backing Strip

Fig. 33. METHOD OF MAKING FLAT BUTT WELD

## LESSON No. 16

### Straight Butt Weld—Plates in the Same Plane

**Conditions**

| | |
|---|---|
| | Same as Lesson No. 13 except |
| Position of plates | Horizontal (see Fig. 33). Note the backing strip. Care should be taken not to direct the arc through the opening onto the backing strip. |
| Current in arc | 140 amperes. |
| Position of electrode | Ahead 15 deg. from perpendicular to point the arc back into the weld. |

**Requirements**

Same as Lesson No. 13.

**Procedure**

Place the plates as shown in Fig. 33, and with an opening of $\frac{3}{16}$ in. at one end and $\frac{1}{4}$ in. at the other. Tack the end with the $\frac{3}{16}$ in. opening. The path of the electrode will be similar to that in Lesson 13 except that the sides of the horseshoe are longer, about $\frac{1}{4}$ to $\frac{5}{16}$ in. Do not carry the arc beyond the edge of the plates or the edges will not be properly fused. Extra metal will run in and only a superficial weld ensue.

**Inspection and Test**

Same as Lesson No. 13.

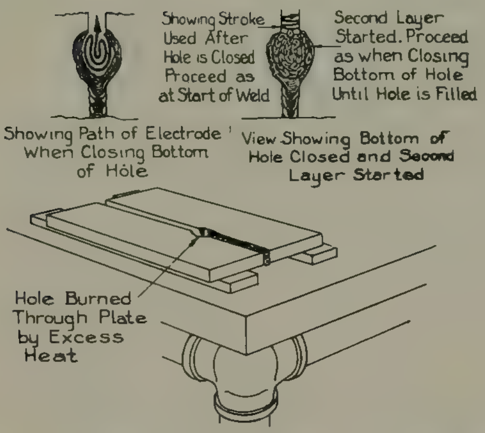

Showing Stroke Used After Hole is Closed Proceed as at Start of Weld
Second Layer Started. Proceed as when Closing Bottom of Hole Until Hole is Filled
Showing Path of Electrode When Closing Bottom of Hole
View Showing Bottom of Hole Closed and Second Layer Started
Hole Burned Through Plate by Excess Heat

Fig. 34. METHOD OF FILLING HOLE IN BUTT WELD CAUSED BY ARC MELTING THROUGH

If the electrode is pointed too far forward, i.e., if it makes an angle of 25 deg. or 30 deg. with the perpendicular, the metal will be coarse grained and possibly oxidized. If it is held too nearly perpendicular, the heat will not be properly distributed in the weld. Too much will be delivered in the middle and too little along the edges. The same result will follow if the arc is not moved slowly along the edges and rapidly across the weld. The penetration will probably be poor at the edges of the weld.

### LESSON No. 16-A

This is the same as Lesson No. 16 except the plates should be spaced $\frac{1}{16}$ in. apart at one end and $\frac{1}{8}$ in. at the other and they should be supported **at least 3 in. from the line of weld, and no backing used.** The current should be reduced to 125 amperes and much greater care taken in moving the arc. The higher current used in Lesson 16 is due to the heat being carried away by the backing strip which was used. The arc will burn through the weld if:

The electrode is held too nearly perpendicular.
The arc is moved too slowly across the weld.
The current value is too high.
The arc is too long. A long arc results in slower deposition of metal. Consequently, in order to fill the weld the arc travel will be slower. The arc crater becomes large and finally falls through.

To patch such a hole reduce the current to 100 amperes. Hold the electrode vertical and weld around the bottom of the hole gradually closing it and building the metal up to the thickness of the plate. (See Fig. 34.)

| **Requirements** | Strong sound weld.<br>Do not burn through.<br>Do not allow any unsightly knobs or warts of metal to run through. |
|---|---|

Inspect break and examine the weld.

### LESSON No. 17

This is the same as Lesson No. 16-A except that the plates are to be so placed that the weld makes an angle of 45 deg. with the horizontal. The lower end nearest the welder should have the narrow spacing between plates. The direction of the weld is upward. The metal should not project more than $\frac{1}{32}$ in. through the back of the weld and should be reasonably smooth. The arc should be kept uniformly short and the electrode inclined slightly more than in Lesson No. 16 to point the arc back into the weld.

Inspect break and examine the weld.

### LESSON No. 18

This is the same as Lesson No. 17 except that the plates are set vertical and the direction of the weld upward.

Inspect break and examine the weld.

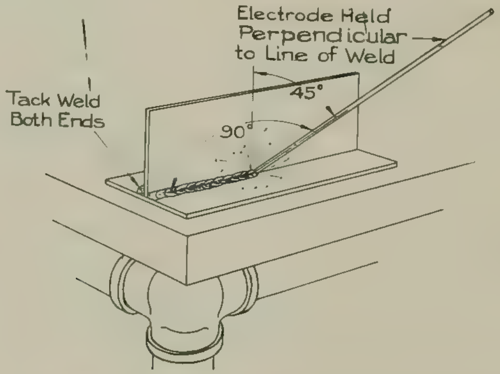


Fig. 35. METHOD OF MAKING SINGLE FILLET T WELD

## LESSON No. 19

### Straight T Single Fillet Weld

**Conditions**

| | |
|---|---|
| Plates | Two plates as in Lesson No. 13. |
| Position of plates | One plate horizontal, the other vertical along middle of first plate (Fig. 35). |
| Position of weld | Flat. |
| Type of joint | Straight T fillet weld on one side only. |
| Direction of travel | Forward. |
| Current in arc | 150 amperes. |
| Position of electrode | Perpendicular to weld—45 deg. from horizontal. |

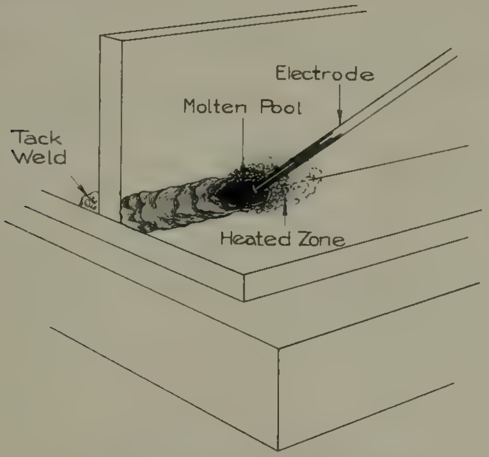


Fig. 36. DIAGRAM SHOWING HEAT DISTRIBUTION IN T WELD

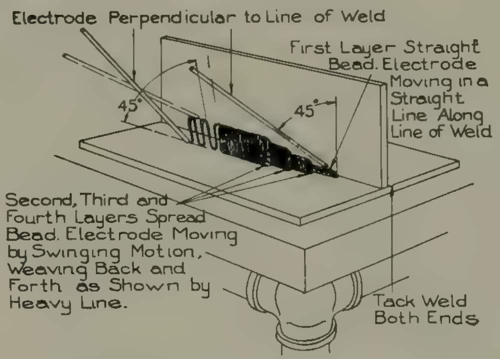

Electrode Perpendicular to Line of Weld
First Layer Straight Bead. Electrode Moving in a Straight Line Along Line of Weld
45°
45°
Second, Third and Fourth Layers Spread Bead. Electrode Moving by Swinging Motion, Weaving Back and Forth as Shown by Heavy Line.
Tack Weld Both Ends

Fig. 37. METHOD OF MAKING A FOUR LAYER T WELD IN HORIZONTAL POSITION

**Requirements**

Uniform sound weld of good appearance. Height of weld same as thickness of plates. Penetration must be carried into angle of joint. Appearance of fracture of deposited metal should be similar to Lesson No. 13.

**Procedure**

The electrode should be moved in a vertical zig-zag path across the weld advancing as fast as necessary to keep the proper height of the deposited metal. Since the weld is being made in the middle of the horizontal plate the heat will be conducted away in both directions by this plate and therefore, at a greater rate than by the vertical plate.

Accordingly, the movement of the electrode and arc should be slower over the bottom plate and somewhat faster on the vertical plate.

A sound weld depends on thorough penetration into the apex of the angle. This requires extra attention since the arc has a tendency to skip over the bottom of a groove. To overcome these difficulties, the metal along the crack should be nearly at the fusing point before the arc reaches it and this result is obtained by allowing the heat of the arc to progress ahead of the weld. In starting the weld, either initially or after the arc has been permitted to go out, the arc should be kept very short and it should be moved rapidly back and forth across the weld without advancing much along the weld. Gradually the metal along the crack will be seen to heat up and form a crater. (See Fig. 36.) As long as the welding continues, this preheating automatically keeps up. If this preheating is not taken care of when starting a weld, there will be a distance, possibly 1 in. long, where the weld is not complete to the bottom but merely runs over the surface of the plates in a form of bridge. Such a spot is very dangerous since such a weakness provides a starting point for a crack.

### Inspection and Test

Same as Lesson No. 13.

In breaking the weld, force the plates together **with the weld between.**

## LESSON No. 20

### Four Layer T Fillet Weld

### Conditions

| | |
|---|---|
| Plates | Two plates as in Lesson No. 13. |
| Position of plates | See Fig. 37. Plates tacked together at each end. |
| Position of weld. | Flat. |
| Type of joint | Straight T fillet weld. |
| Current in arc | 130 amperes. |
| Position of electrode | Perpendicular to weld. |
| | Four layers of weld, each approximately $\frac{1}{8}$ in. thick. This type of weld is frequently used for joints which must remain tight under pressure. |

### Requirements

Clean uniform surface indicating penetration into plates at edges of weld. No signs of porosity. Surface of weld should be flat across, not reinforced or concave.

Clean surface of each layer with hammer and chisel and brush before depositing a succeeding layer.

### Procedure

The deposition of the first layer is similar to Lesson No. 13. Clean and proceed with second, third and fourth layers. Unless the scale is thoroughly cleaned off, it will tend to provide a path for leakage.

This leakage is very difficult to locate and stop because of the path through the weld. It first passes through a porous spot in the first layer, then along the oxide plane or surface between layers to a porous spot in the next layer, and so through the entire weld. The outlet may be several inches from the inlet on the other side of the weld. In heavy welds for strength only, a break will follow a similar path.

To keep the surface of the weld flat, or to make what is called a flush weld of the second, third and fourth layers, the arc should be moved quite rapidly across the middle of the weld and more slowly at the edges. By exaggerating this motion, the weld may be made concave. The motion is a zig-zag motion across the weld advancing slowly along the weld.

**Inspection and Test**

Do not break this weld. The appearance and the care taken during welding will be depended on as a test.

## LESSON No. 21

### Four Layer T Fillet Weld

**Conditions**

Same as Lesson No. 20 except
Plates and line of weld vertical
Travel—upward.

**Requirements**

Same as Lesson No. 20.

**Procedure**

Same as for Lesson No. 20, as modified by vertical position of weld. (See Fig. 38.)

**Inspection and Test**

## LESSON No. 22

### Three Parallel Beads

**Conditions**

Similar to Lesson No. 2, with plate vertical and bead horizontal.

| | |
|---|---|
| Position of plate | Vertical. |
| Type of bead | Spread bead. |
| Position of weld | Horizontal—travel left to right. |
| Current in arc | 100 amperes. |
| Position of electrode | Horizontal—perpendicular to plate. |

**Requirements**

Three parallel beads, each 10 in. long, ⅜ in. wide, and $\frac{3}{16}$ in. high with a space ½ in. wide between rows. One layer. Beads to be straight, uniform in width and height and with no appreciable sagging. (See Fig. 39.)

**Procedure**

Due to the tendency of the metal to run or sag, the difficulty will be to keep the lower edge of the bead straight and also to keep the metal from running and making the lower edge of the weld thicker than the upper edge.

The only way to achieve this is to maintain a very short arc as brought out in Lesson No. 9.

**Inspection**

Inspection, only, required.

## LESSON No. 22—Cont'd

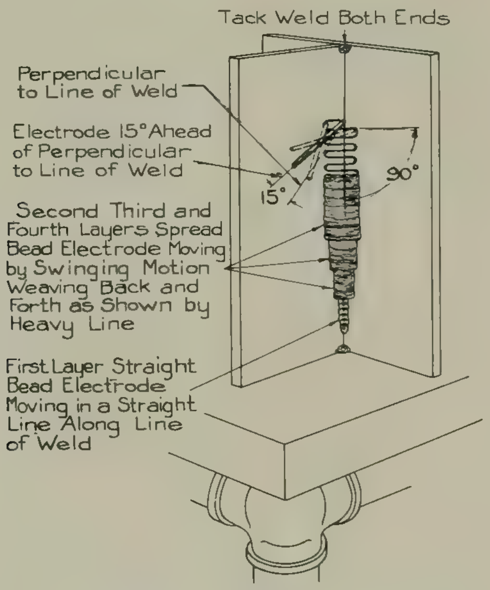

Tack Weld Both Ends
Perpendicular to Line of Weld
Electrode 15° Ahead of Perpendicular to Line of Weld
15°
90°
Second Third and Fourth Layers Spread Bead Electrode Moving by Swinging Motion Weaving Back and Forth as Shown by Heavy Line
First Layer Straight Bead Electrode Moving in a Straight Line Along Line of Weld

Fig. 38. METHOD OF MAKING A FOUR LAYER T WELD IN A VERTICAL POSITION

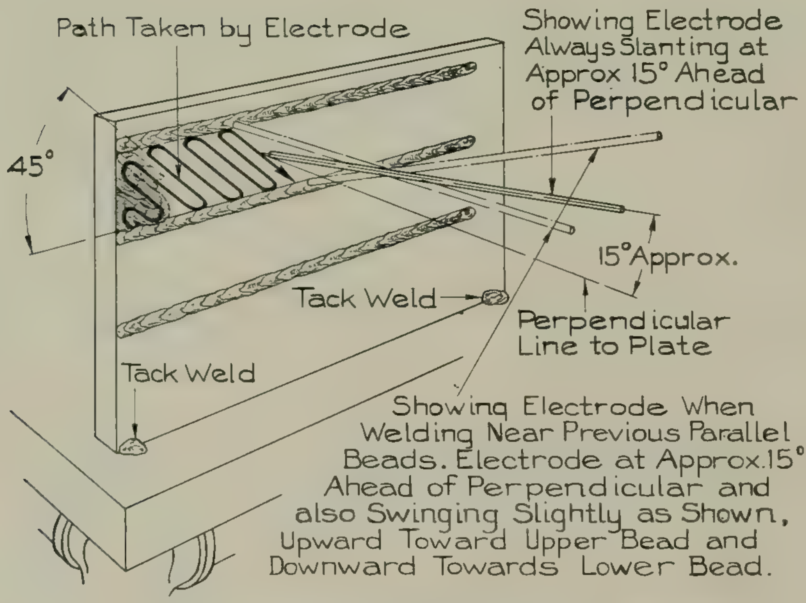

Path Taken by Electrode
Showing Electrode Always Slanting at Approx 15° Ahead of Perpendicular
45°
15° Approx.
Tack Weld
Perpendicular Line to Plate
Tack Weld
Showing Electrode When Welding Near Previous Parallel Beads. Electrode at Approx. 15° Ahead of Perpendicular and also Swinging Slightly as Shown, Upward Toward Upper Bead and Downward Towards Lower Bead.

Fig. 39. METHOD OF FILLING IN BETWEEN PARALLEL HORIZONTAL SPREAD BEADS ON VERTICAL PLATE

## LESSON No. 23

### Filling Space Between Beads Made in Lesson No. 22

**Conditions**

| | |
|---|---|
| | Same as Lesson No. 22, except |
| Type of bead | Straight bead. |
| Current in arc | 125 amperes. |

**Requirements**

Weld made in one layer, the same height as previous beads. Weld must penetrate into plate and into beads at either side. (See Fig. 40.)

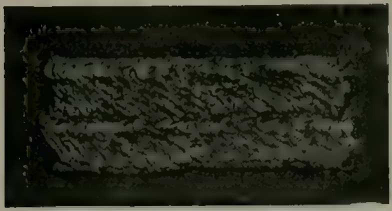


Fig. 40. APPEARANCE OF FINISHED PATCH, LESSON 23

**Procedure**

See Fig. 39 for travel of electrode, the path being at an angle of 45 deg. Electrode should point back 15 deg., to direct the arc into the angle where weld is being made between bead and plate. At the top, the electrode should be pointed slightly upward to direct the arc onto the lower side of the upper bead. At the bottom, the electrode should be directed slightly downward against the edge of the lower bead. Do not overlook the cleaning of the metal during welding.

**Inspection and Test**

Inspect surface for smoothness. Chip off part of deposit to inspect penetration into plate and into upper and lower side beads.

## LESSON No. 24

### Patching Exercise—Building Up Metal

**Conditions**

| | |
|---|---|
| Position of plate | Vertical. |
| Type of bead | Spread bead. |
| Position of weld | First bead horizontal, subsequent beads flat. |
| Current in arc | 110 amperes. |
| Position of electrode | Horizontal, perpendicular to plate for first bead. For subsequent beads incline slightly to direct arc downward into angle between preceding bead and plate. |

## LESSON No. 24—Cont'd

**Requirements**

One layer patch 1/8 in. high, 6 to 8 in. long and 4 in. wide built of adjacent beads, each 1/4 in. wide and 1/8 in. high laid horizontally across plate, one above the other. Uniform height and smooth surface of patch. (See Fig. 41.)

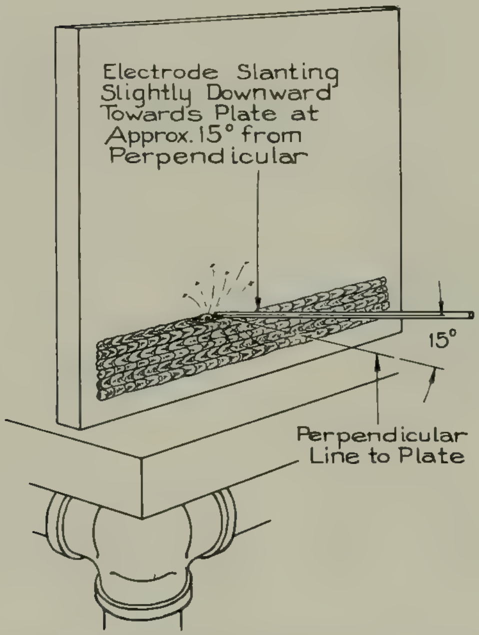

Electrode Slanting Slightly Downward Towards Plate at Approx. 15° from Perpendicular
15°
Perpendicular Line to Plate

Fig. 41. METHOD OF BUILDING UP A PATCH ON A VERTICAL PLATE WORKING UPWARD

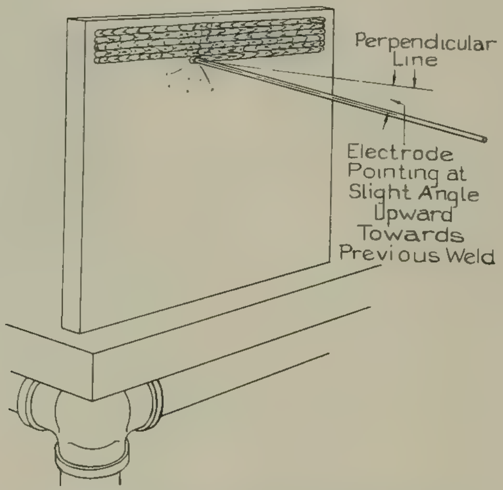

Perpendicular Line
Electrode Pointing at Slight Angle Upward Towards Previous Weld

Fig. 43. METHOD OF BUILDING UP A PATCH ON A VERTICAL PLATE WORKING DOWNWARD

Fig. 42. APPEARANCE OF FINISHED PATCH ON VERTICAL PLATE

**Procedure**

Deposit one bead horizontally near bottom of plate as in Lesson No. 22. Deposit another bead above first one and close enough to avoid any appreciable depression between beads. Continue until width of patch is 4 in.

**Inspection and Test**

Inspect surface for regularity. Chip off a portion to inspect penetration. (See Fig. 42.)

## LESSON No. 25

### Patching Exercises—Building Up Metal

**Conditions**

Same as Lesson No. 24 except electrode inclined slightly to direct the arc upward on subsequent beads.

**Requirements**

Same as Lesson No. 24 except beads deposited from top downwards. (See Fig. 43.)

**Procedure**

Same as Lesson No. 24 except deposit first bead at top of plate, and the next one below it. Direct the arc slightly upward into the upper bead.

**Inspection and Test**

Same as Lesson No. 24.

**Comments**

In practice, pads on vertical surfaces are built up as in Lesson No. 24 since it is easier to secure good penetration when working on top of a surface where this can be done. Lesson No. 25 is principally for the purpose of giving preliminary training for later lessons.

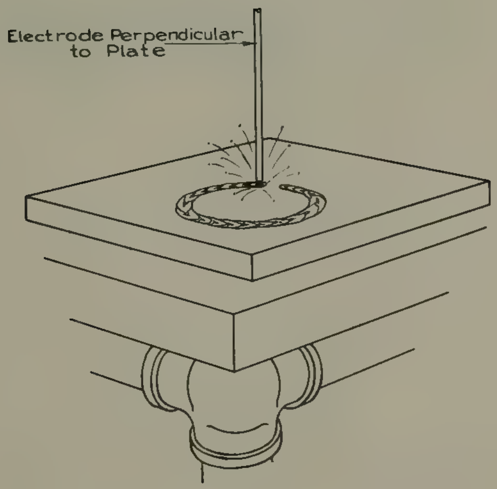


Fig. 44. METHOD OF DEPOSITING CIRCULAR BEAD

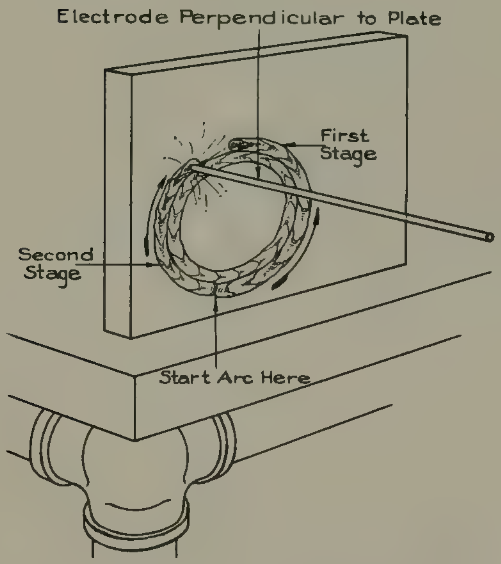


Fig. 45. METHOD OF WELDING AROUND TUBES

## LESSON No. 26

### Beading

**Conditions**

| | |
|---|---|
| Position of plate | Horizontal. |
| Type of bead | Straight or slightly spread. |
| Position of weld | Flat. |
| Current in arc | 100 amperes. |
| Position of electrode | Vertical—perpendicular to plate. |

**Requirements**

Circular bead—2 in. in diameter, ¼ in. wide and $\frac{3}{16}$ in. high. (See Fig. 44.) The bead should be uniform in width and height and circular in form.

**Procedure**

Same as Lesson No. 1 except line of weld is circular.

**Inspection**

Inspection, only, needed.

## LESSON No. 26-A

**Conditions**

Same as Lesson No. 26 except plate vertical. Use plate from Lesson No. 26, with circular bead welded on.

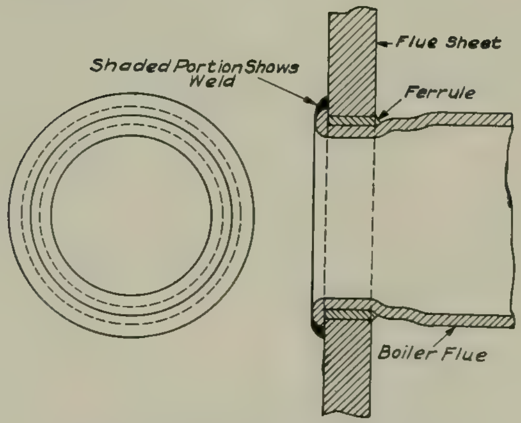


Fig. 46. CROSS SECTION OF FLUE OF LOCOMOTIVE SHOWING METHOD OF WELDING TUBE TO TUBE SHEET

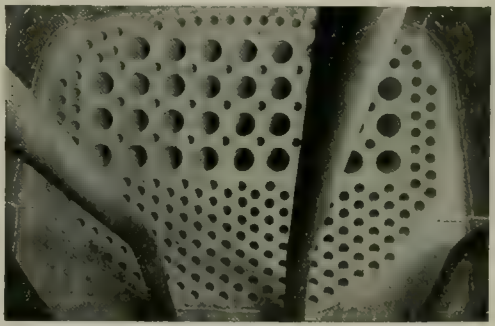


Fig. 47. VIEW OF BACK FLUE SHEET OF LOCOMOTIVE FIRE BOX SHOWING WELDED TUBES

**Requirements**

Weld a second bead outside the circular bead on the plate made in Lesson No. 26, this simulating the welding of flues and tubes in locomotives and similar applications. The second bead should be smooth of uniform width and height. The height should be the same as that of the first bead. The beads should be joined closely together with only a very shallow depression between as in Lessons No. 24 and 25.

**Procedure**

Start the weld at about ¾ in. to the left of the bottom. (See Fig. 45.) Weld to the right and upward to the top. Then go back to the starting point and weld upward to the left and close at the top. Particular attention should be given to securing a tight weld at the starting and finishing points since such a weld under service conditions must be tight under high pressure. (See Figs. 46 and 47.)

The first trials will probably result in the bead being wider at the bottom than at the top, with a piling up of the metal at the top and a thicker weld. A short arc and uniform speed of travel are imperative.

## LESSON No. 27

### Straight Flat Lap Weld

**Conditions**

| | |
|---|---|
| Position of plate | Horizontal. (See Fig. 48.) |
| Position of weld | Flat |
| Type of joint | Straight flat lap weld. |
| Direction of travel | Forward. |
| Current in arc | 150 amperes. |
| Position of electrode | Perpendicular to weld, 45 deg. from horizontal. |

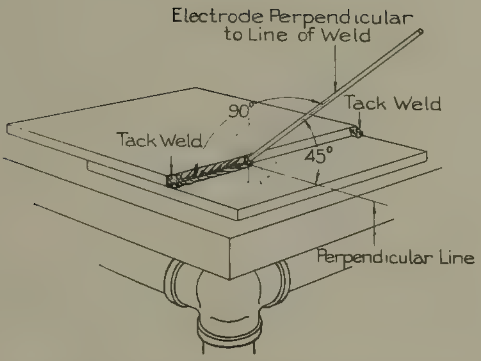


Fig. 48. METHOD OF MAKING STRAIGHT FLAT LAP WELD, WITH PLATES HORIZONTAL

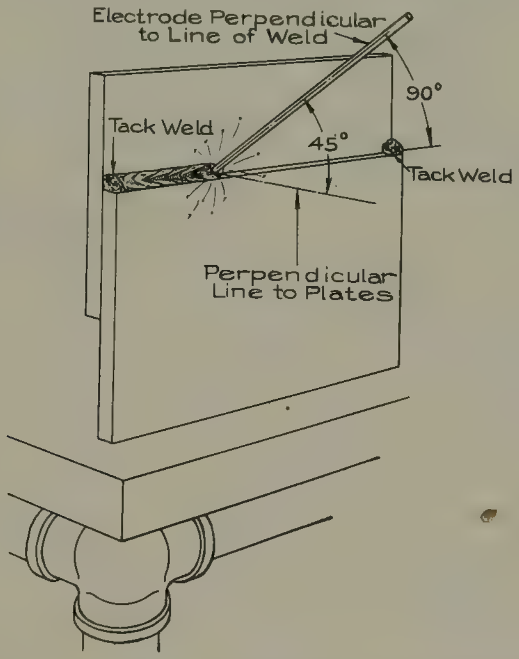

Electrode Perpendicular to Line of Weld
90°
Tack Weld
45°
Tack Weld
Perpendicular Line to Plates

Fig. 49. METHOD OF MAKING STRAIGHT FLAT LAP WELD WITH PLATES VERTICAL AND METAL DEPOSITED DOWNWARD

## LESSON No. 27—Cont'd

**Requirements**

Smooth weld, penetration well into apex of angle between plate surfaces jointed. The grain of the metal in the weld should be found of dull gray color with no black spots or lines. Tack the plate with approximately 2 in. lap and proceed in general as in Lesson No. 19. Weld only one side so that weld may be broken open.

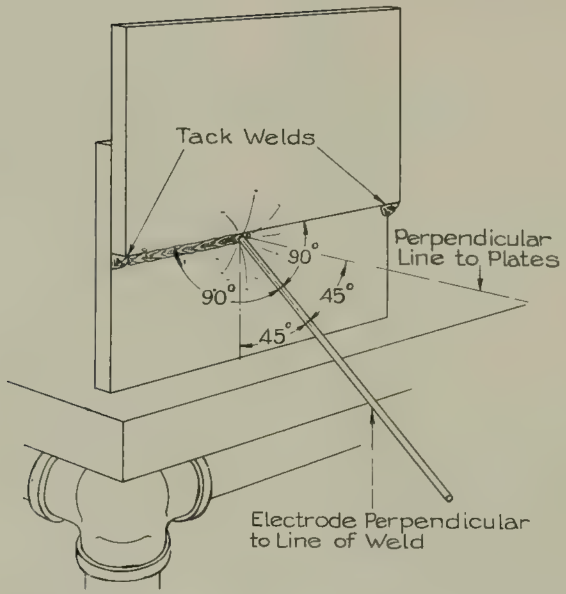

Tack Welds
Perpendicular Line to Plates
90°
90°
45°
45°
Electrode Perpendicular to Line of Weld

Fig. 50. METHOD OF MAKING STRAIGHT FLAT LAP WELD WITH WELD REVERSED FROM FIG. 49

**Inspection and Test**

After inspection break weld. Black or dark spots, lines or surfaces indicate improper fusion and penetration.

## LESSON No. 28

### Straight Flat Lap Weld

**Conditions**

Same as Lesson No. 27 except plates vertical with lower plate on side toward welder. (See Fig. 49.)

**Requirements, Procedure, Inspection, and Test**

Same as Lesson No. 27.

## LESSON No. 29

### Straight Overhead Lap Weld

| | |
|---|---|
| **Conditions** | Same as Lesson No. 27 except upper plate on side nearest welder. (See Fig. 50.) |
| Electrode position | Perpendicular to weld, pointed at angle of 45 deg. to horizontal to direct arc up against under side of upper plate. |

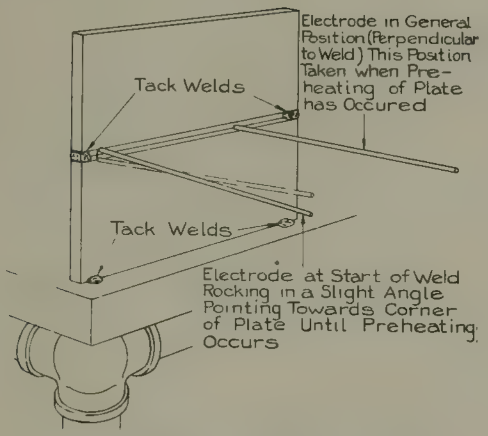

Electrode in General Position (Perpendicular to Weld) This Position Taken when Pre-heating of Plate has Occured
Tack Welds
Tack Welds
Electrode at Start of Weld Rocking in a Slight Angle Pointing Towards Corner of Plate Until Preheating Occurs

Fig. 51. METHOD OF MAKING STRAIGHT HORIZONTAL BUTT WELD

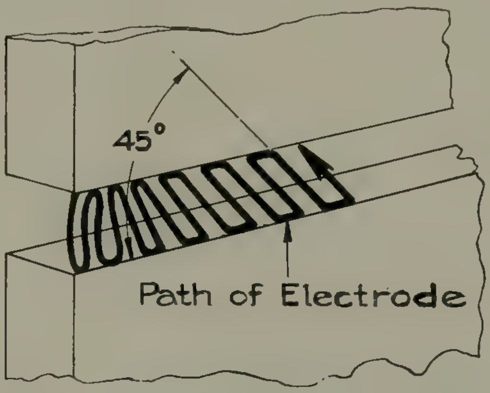


Fig. 52. MANNER OF ELECTRODE TRAVEL IN MAKING WELD OF FIG. 51

| | |
|---|---|
| **Requirements** | Same as Lesson No. 28. |
| **Procedure** | Same as Lesson No. 28 except short arc imperative. |
| **Inspection and Test** | Same as Lesson No. 28. |

## LESSON No. 30

### Straight Horizontal Butt Weld

**Conditions**

| | |
|---|---|
| Position of plates | Vertical. (See Fig. 51.) |
| Position of weld | Horizontal. |
| Type of joint | Straight butt weld—flush or slightly reinforced. |
| Current in arc | 150 amperes. |
| Position of electrode | In general the electrode should be held in a horizontal position perpendicular to the weld. In first starting the weld, the electrode may be rocked through a small angle, pointing slightly upward to direct the arc against the edge of the upper plate, and downward to direct the arc against the corner plate. After the weld is well started and the heat has advanced in the metal, the edges of the plates will melt down ahead of the arc, thus automatically forming a bevel or groove so the arc can reach the back of the weld. |

## LESSON No. 30—Cont'd

**Requirements**

Weld of good appearance, smooth on both sides, penetration into both plates and quality of metal in weld as in Lessons 13 and 27.

**Procedure**

The plates are separated further in this lesson than in Lesson No. 13 and tacked in order to permit penetration to the back of the plates. After the well is well started, the electrode should move in a zig-zag path, with the zig-zags tilted backward about 45 deg. (See Fig. 52.) Since the flame and hot gases from the arc will rise and heat the upper plate, it is necessary to make up for this by directing the arc more against the lower than the upper plate, by slowing the electrode down when it is directed toward the lower plate. Do not use a complete horseshoe path as in Lesson No 13, or the front of the weld will be closed over without penetration to the back.

**Inspection and Test**

Inspect and break weld.

## LESSON No. 31

### Inch per Inch

| | |
|---|---|
| **Conditions** | Same as Lesson No. 1 except the bead is deposited on the under side of a flat plate. |
| Position of weld | Overhead. |
| Current in arc | 125 amperes. |
| Position of electrode | Vertical, perpendicular to plate, the arc directed upwards. |
| **Requirements** | Same as Lesson No. 1. |

**Procedure**

Tack supporting plates as shown in Fig. 53 to raise plate on which beads are to be deposited and make possible a more comfortable position. This lesson will probably require more practice than any of the preceding ones. The tendency will be for the metal to run and hang down in warts. This condition can be prevented and satisfactory deposition attained by holding a very short arc and uniformly advancing the electrode. Lengthening the arc slightly will cause the metal to run and hang down. Still further lengthening of the arc will prevent any deposition whatever. A wart may be burned off by playing a long arc on it for a short time and then by quickly shortening the arc, the welding may proceed.

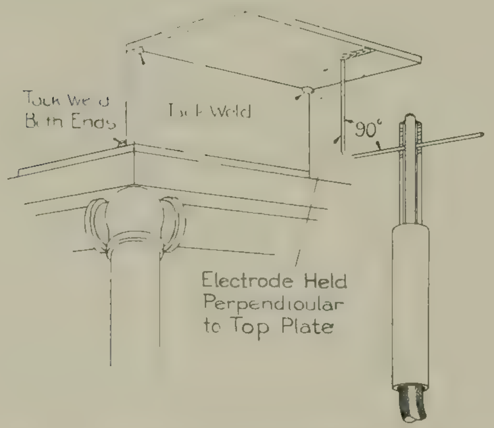


Fig. 53. ILLUSTRATION OF OVERHEAD WELDING

**Inspection and Tests**

Same as Lesson No. 1.
The requirements as to appearance will not be so strict as in Lesson No. 1 as generally an overhead weld is more rough than any other type. Penetration, etc., should however be insisted upon.

## LESSON No. 32

### Three Parallel Beads

**Conditions**

Same as Lesson No. 2 except

| | |
|---|---|
| Position of weld | Overhead. |
| Current in arc | 125 amperes. |
| Position of electrode | Ahead 15 deg. to 30 deg. from perpendicular to point arc back into weld. |

**Requirements**

See also Lesson No. 2. Three parallel beads, each 10 in. long, $\frac{3}{8}$ in. wide and $\frac{3}{16}$ in. high with a space $\frac{1}{2}$ in. wide between rows. Each bead to have same qualities as in Lesson No. 31.

**Procedure**

Proceed as in Lesson No. 31 spreading the bead slightly to meet the requirements as to width. This zig-zag motion of the arm will be found to relieve the strain on the muscles and this lesson will probably be considerably easier than Lesson No. 31. Directing the arc back into the weld will pile up the metal to the required height. **Keep the arc short.**

**Inspection and Test**

Same as Lesson No. 2

## LESSON No. 33

### Filling Space Between Welds Made in Lesson No. 32

**Conditions**

Same as Lesson No. 4 except

| | |
|---|---|
| Position of weld | Overhead. |
| Current in arc | 125 amperes. |
| Position of electrode | As in Lesson No. 32. |

**Requirements**

Same as Lesson No. 4.
See also Lessons Nos. 31 and 32.

**Procedure**

See Lessons Nos. 4, 31 and 32.

**Inspection and Test**

See Lessons Nos. 4, 31 and 32.

## LESSON No. 34

### Straight Butt Weld—Plates in Same Plane

**Conditions**

| | |
|---|---|
| Position of plates | Horizontal. Tack with $\frac{3}{16}$ in. opening at beginning and $\frac{1}{4}$ in. opening at the end where the weld finishes. |
| Position of weld | Overhead. |
| Type of joint | Straight—butt weld. |
| Direction of travel | Forward. |
| Current in arc | 125 amperes. |
| Position of electrode | Backward 15 deg. to 30 deg. from perpendicular to direct arc ahead of weld. |

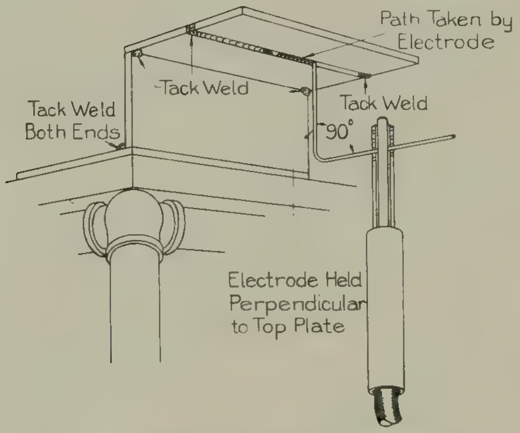


Fig. 54. METHOD OF MAKING AN OVERHEAD STRAIGHT BUTT WELD

**Requirements**

Same as Lessons Nos. 16-A and 13, also modified by Lesson No. 31.

**Procedure**

The path of the electrode will be as in Lesson No. 16-A, page 40. (See Fig. 54.) This weld will be reinforced on the lower side, but it should penetrate entirely through to the back of both plates. (See Figs. 33 and 34.) Pointing the electrode ahead assists in driving through and also keeps the metal from piling up too much on the under side.

**Inspection and Test**

Same as Lesson No. 16-A

## LESSON No. 35

### Three Layer—Straight Overhead Lap Weld

**Conditions**

| | |
|---|---|
| Plate | Two plates ⅝ to ¾ in. thick, 12 in. or more in length. |
| Position of plates | Vertical as in Lesson No. 29. (See Fig. 50.) |
| Position of weld | Overhead. |
| Type of joint | Straight lap weld. |
| Current in arc | First layer—200 amperes.<br>Second layer—175 amperes.<br>Third layer—150 amperes. |
| Electrode | $\frac{5}{32}$ in. diameter. |
| Position of electrode | First layer—perpendicular to weld 45 deg. from horizontal, with arc directed upwards. Succeeding layers 45 deg. from horizontal, arc directed upwards. Electrode inclined 15 deg. forward to direct arc back into weld. |

**Requirements**

Same as Lesson No. 29.

Fig. 55. ILLUSTRATION OF METHOD OF MAKING A THREE-LAYER STRAIGHT OVERHEAD LAP WELD

**Procedure**

The first layer should be a straight bead along the apex of the angle in which the weld is made. (See Fig. 55.) The heavy current is made necessary by the thickness of the plates. This involves more rapid feeding of the electrode as it is consumed faster. In subsequent layers the electrode should be moved in a zig-zag path with the lower edge of the weld in advance. See Fig. 39, for Lesson No. 23.

## LESSON No. 36

### Straight Vertical Two-Man Butt Weld

**Conditions**

| | |
|---|---|
| Plates | Two plates ½ to ¾ in. thick, 24 in. long and 12 in. wide. |
| Position of plate | Vertical. |
| Position of weld | Vertical—weld upward. |
| Type of joint | Straight butt joint. |
| Current in arc | 150 amperes. |
| Electrode | $\frac{5}{32}$ in. diameter. |
| Position of electrode | As in Lesson No. 18. |

**Requirements**

Same as Lesson No. 18.

**Procedure**

Tack the plates with ⅜ in. opening at one end of the plate and ⅝ in. at the other. Set in a vertical position with the ⅜ in. gap at the bottom. Locate the plates so that two operators can weld at the same time, one on each side. The weld is started at the bottom, each man welding through to the middle of the plate and they should keep even throughout the weld.

**Inspection and Test**

Same as Lesson No. 18.

## LESSON No. 37

### Filling Holes in a Plate

**Conditions**

| | |
|---|---|
| Plate | ⅝ in. to ¾ in. thick with 6 holes drilled 1 in. in diameter. |
| Position of plate | Flat for 3 holes and vertical for 3 holes. |
| Current in arc | 125 amperes. |
| Electrode | ⅛ in. diameter. |

**Requirements**

Smooth tight weld that will not permit kerosene oil to work through.

**Procedure**

*Flat position*

Weld a bead inside around the edge of one of the holes. (See Fig. 56.) Brush and weld another inside of the first, thus gradually closing the hole over without building up above the surface of the plate. Then turn the plate over, chip out all scale inside the hole and put in a layer of metal on the bottom layer, securely welding to the sides of the hole. Clean this surface and continue until hole is filled. (Fig. 56.)

**Procedure—Cont'd**

*Vertical position*

Build a layer across bottom of hole and build up on this until hole is closed. Turn plate around and clean out scale and oxide. Build up a layer of metal on the vertical surface now forming the back of the hole and proceed forward and upward to close the hole. (Fig. 56.)

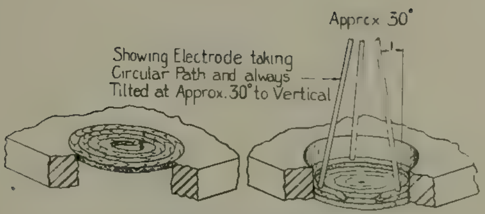

Approx 30°
Showing Electrode taking Circular Path and always Tilted at Approx. 30° to Vertical

**Fig. 56.** METHOD OF FILLING HOLES IN A HORIZONTAL PLATE

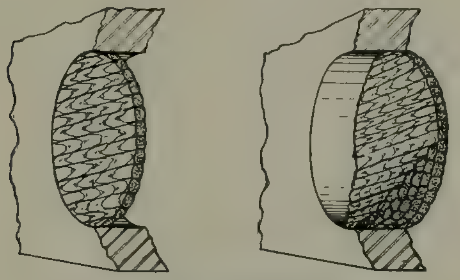


**Fig. 57.** METHOD OF FILLING HOLES IN A VERTICAL PLATE

**Inspection and Test**

Test with kerosene oil.

In many cases of tanks made of ½-in. plate or thinner metal, it is impossible to get at the back of the plate. In such a case the hole must be closed from one side. In the flat position a weld should be made around the bottom of the hole. (See Fig. 56.) Then another one made inside of this and thus the bottom of the hole is closed. Then repeat with another layer on top of the first and by continuing in this way, gradually fill the hole. Care should be taken to secure penetration on the side walls of the hole.

In a vertical plate close the back of the hole by welding successive beads across the hole. Then by building upward and outward the hole is closed. (See Fig. 57.)

The preceding part of Part II has been devoted entirely to instruction for the use of the metallic electrode in welding steel. The general principles and methods outlined are applicable to **simple** welds of structural or forged steel, wrought iron, plate steel and for cast steel having a carbon content below 0.40 per cent. The remainder of Part II consists of instructions concerning the use of the Carbon and Graphite electrodes.

## DETAILED INSTRUCTIONS ON EXERCISES (CARBON ARC)

There will be required a source of welding current which will deliver a maximum of from 400 to 600 amperes and down to a minimum of about 40. A carbon electrode holder and electrodes of various sizes will be needed. While the hand shield may be used in cutting, it will be necessary to use both hands in welding and therefore the helmet must be used.

### The Electrode

The holder should grip the electrode from 4 to 5 in. from the end. The electrode should preferably be tapered to a blunt point at the working end to keep the arc from wandering over the end of the electrode. As the electrode burns away with use, the holder is moved back along the electrode to keep the length of working carbon constant. The burning away of the electrode will tend to keep the taper approximately constant.

### Striking the Arc

The carbon arc is very stable and easy to maintain. The length can be varied over wide limits without causing the arc to go out. There is no tendency for the electrode to freeze or stick as in the case of the metallic electrode. Accordingly, the arc can be struck without difficulty at any point and rapidly moved over the surface of the work to the point where the weld is to be made.

### Depositing Metal

In order for two masses of metal to unite under the conditions encountered in arc welding, it is necessary that the adjoining surfaces, at least, are thoroughly fused so the metal can flow. In welding with the carbon electrode, a molten pool should be formed on the work and the added metal deposited in this pool. The arc should be kept at this point until the added metal is thoroughly melted and mixed with the original metal before more material is added. Usually the added metal is in the form of a long stick of filler rod held in the welder's left hand. When the pool or the work is ready, the end of the filler rod is inserted in the pool and the arc directed against the rod just above the surface of the molten metal. This will melt through the rod and leave the end in the molten pool on the work. The arc should be played about on the pool until the added metal is all melted down, when due to the circulation caused by the heat, the molten metal will be well mixed. After this, the filler rod may be again inserted in the pool and the process repeated, advancing along the line of weld.

### Position of Electrode

In welding or building up, the electrode is generally held perpendicular to the surface of the plate, but is inclined ahead about 15 deg. to the line of weld to direct the arc back into the weld. (See Fig. 58.)

### Direction of Travel

By welding from left to right, a right-handed welder avoids awkward positions. (See Fig. 58.) The arc is directed backward into the weld and the position of the arms and hands is comfortable.

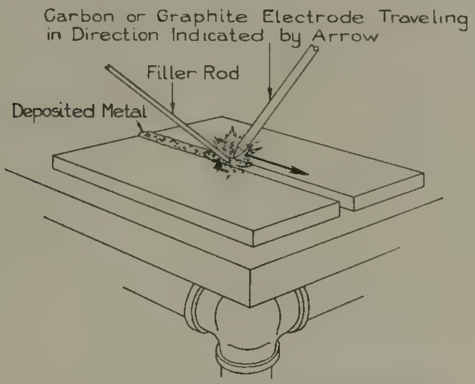

Carbon or Graphite Electrode Traveling in Direction Indicated by Arrow
Filler Rod
Deposited Metal

Fig. 58. DIRECTION OF TRAVEL IN MAKING A CARBON WELD

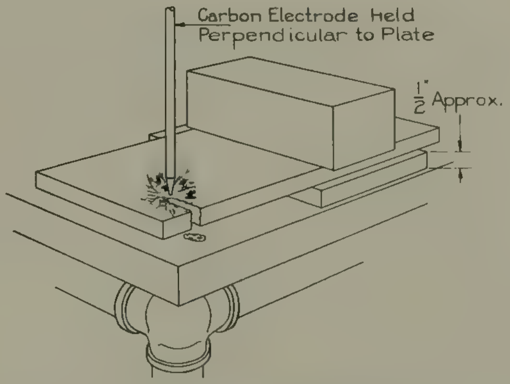


Fig. 59. CUTTING A STEEL PLATE WITH A CARBON OR GRAPHITE ELECTRODE

## LESSON A

### Cutting

| | |
|---|---|
| **Material** | Scrap steel plate, ½ in. or more in thickness, large enough to make straight cut of several inches. |
| Position of plate | Horizontal with supports to raise it ½ in. or more from table (Fig. 59) or overhang (Fig. 60). |
| Electrode | Carbon or graphite ½ in. or ¾ in. diameter. |
| Position of electrode | Vertical. |
| Arc current | 400 to 600 amperes. |
| Direction of travel | Right to left. |

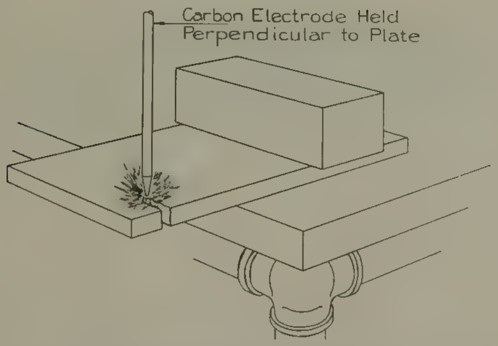


Fig. 60. CUTTING A STEEL PLATE WITH A CARBON OR GRAPHITE ELECTRODE

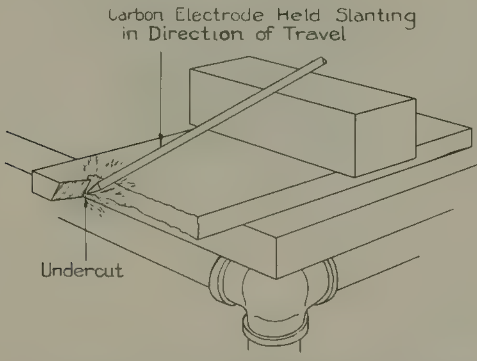


Fig. 61. METHOD OF UNDERCUTTING TO ALLOW MOLTEN METAL TO RUN OUT MORE EASILY

| | |
|---|---|
| **Procedure** | Space must be left under the plate for the molten metal and slag to run out of the cut. Strike the arc at the edge of the plate and hold it still until the metal melts and drops away. |

### LESSON A—Cont'd

Then advance the electrode, trying to keep the arc directed on the metal at the end of the cut by keeping it close to the point where the arc should be directed, and away from the sides of the cut. The electrode should be kept in a vertical position and the end will be down in the groove. Repeat, slanting the electrode backward to direct the arc ahead in the direction of travel. (See Fig. 61.) First melt away the lower part of the plate and then bring the arc toward the top. This undercutting makes it easier for the molten metal to run out. It is particularly beneficial in cutting heavy parts such as castings, shafts, etc. It is often necessary to follow the molten metal down with the arc to keep it fluid until it runs off.

The width of the cut will depend on the size of the electrode used and on the skill of the operator in keeping to a straight line. (See Fig. 62.) The cut will be slightly wider than the diameter of the electrode in order to allow the arc to be played on the bottom of the cut, and it will be wider for thick sections than for thin ones. The edges of the cut will not be smooth, due to masses of the molten metal not running away and also to the fact that the arc will tend to jump from one point to another and cause an uneven cut.

However, cutting with the carbon arc has one advantage in that scale, either on the surface or in pockets, cold shuts, sand-pockets, and blowholes have no appreciable effect on the cut and do not extinguish the flame or arc as they do when gas is used for cutting.

## LESSON B

### Building Up

### Comparison of Carbon and Metallic Electrodes

**Material**

Plate ⅝ in. or more in thickness. Mark two with crayon squares, 4 in. on a side. With the metallic electrode build up walls about ⅞ in. high, making two pens of equal size. (See Fig. 63.)

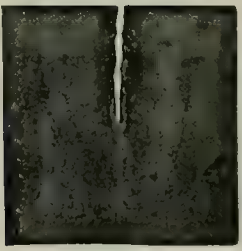


Fig. 62. APPEARANCE OF CUT IN STEEL PLATE

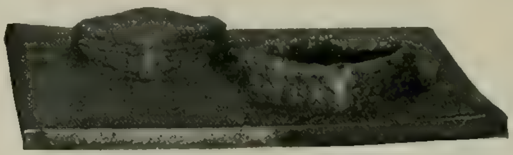


Fig. 63. APPEARANCE OF PEN BEFORE AND AFTER FILLING WITH THE ELECTRIC ARC

**Procedure**

Use ¼ in. metallic electrode and 200 to 300 amperes, or as much as the welder is able to use. Fill the first pen and note the time. To fill the second pen use a ½- or ¾-in. carbon electrode and about 400 amperes. Follow the directions given on page 58 and be certain that the filler rod is not added until the pool on the work is thoroughly melted.

## LESSON C

### Welding

| | |
|---|---|
| **Material** | Two plates ½ in. thick, no bevel, about 24 in. long. |
| Electrode | ½- or ¾-in. carbon. |
| Position of work | Horizontal, plates tacked ¼ in. to ⅜ in. apart at one end and ½ in. at other. |
| Current in arc | 300 amperes. |
| Filler rod | ¼ in. diameter. |
| Position of electrode | Inclined ahead 15 deg. to direct arc back into weld. |

**Procedure**

Begin at end where plates are close together. Fuse the work in a horseshoe shape working forward along the edges of the plates about 1 in. (See Fig. 64.) This will melt down the edges of the plates. Add filler metal at the back of the horseshoe.

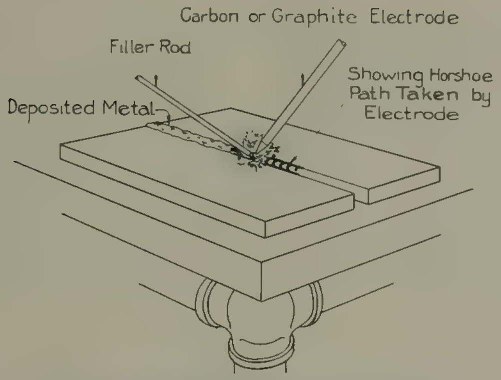

Carbon or Graphite Electrode
Filler Rod
Showing Horshoe Path Taken by Electrode
Deposited Metal

Fig. 64. ELECTRODE TRAVEL IN MAKING A BUTT WELD WITH THE CARBON ARC

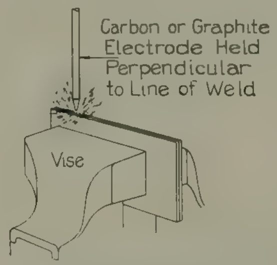

Carbon or Graphite Electrode Held Perpendicular to Line of Weld
Vise

Fig. 65. WELDING THE EDGES OF TWO THIN PLATES WITH THE CARBON ARC

**Inspection and Test**

Inspect, break and examine the weld. If the arc is kept on a small area for too long a time, the metal will be overheated and boil. In this condition it froths and will be spongy and porous when cool. The welding should progress fast enough to avoid this condition.

## LESSON D

### Edge Weld of Thin Sheet Metal

| | |
|---|---|
| **Material** | 2 strips of $\frac{1}{16}$-in. to ⅛-in. sheet steel, 1 to 1½ in. wide and 6 to 10 in. long. Clamp in vise as shown in Fig. 65. The edges should lie together throughout the length. |
| Electrode | ¼ in. diameter sharpened to long taper and ⅛ in. diameter at end. |
| Arc current | 40 amps. for $\frac{1}{16}$-in. sheets to 75 amps for ⅛-in. strips. |

## LESSON D—Cont'd

**Procedure**

Strike the arc at one end and move it along the edge of the sheets, fusing them together. Turn the strips over and weld the other edge in the same way.

**Inspection and Test**

Inspect for smoothness of surface, and absence of porous spots. Also weld should be deep enough to provide a good bond. Clamp the finished piece in the vise with the end uppermost, drive a cold chisel between the strips to wedge them apart and tear the weld. Note the strength and general characteristics. (See Fig. 66 for a type of service weld.)

## LESSON E

### Lap Weld of Thin Sheet Metal

**Material**

2 strips of $\frac{1}{32}$- to $\frac{3}{32}$-in. sheet steel, 1½ to 2 in. wide and 6 to 10 in. long.

Position of work

(See Fig. 67.) Place the strips so they overlap ¾ in. and secure in this position by weights or clamps.

Electrode

Same as for Lesson D.

Arc current

70 amperes for $\frac{1}{16}$-in. strips to 140 amps. for ⅛-in. strips.

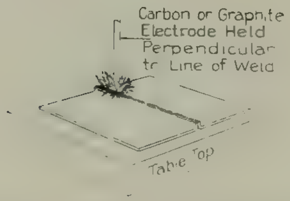

Carbon or Graphite Electrode Held Perpendicular to Line of Weld
Table Top

Fig. 66. A TYPE OF SERVICE WELD USED ON THIN SHEET METAL

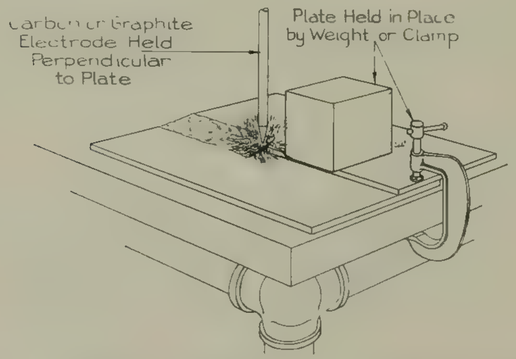

Carbon or Graphite Electrode Held Perpendicular to Plate
Plate Held in Place by Weight or Clamp

Fig. 67. METHOD OF MAKING LAP WELD ON THIN SHEET METAL WITH THE CARBON ARC

**Procedure**

The line of weld will be along the middle of the overlapped portion. Strike the arc at one end and slowly move it along the line of weld. The heat of the arc should fuse through the upper strip and into the lower. This depends on both the current and rate of travel of the electrode along the weld. Penetration can be increased by reducing the rate of travel

| | |
|---|---|
| **Procedure—Cont'd** | until a point is reached where the heat spreads out too wide on the upper strip and causes the fusion of a wide area. When this condition is found, increase the current and travel the electrode faster. Experience will show the best combination to use. |
| **Inspection and Test** | Inspect the back of the lower plate. It should show that the metal was almost fused through. This will be indicated by small flattened drops just forming and the heated appearance along the weld. Grip one strip in the vise and tear the other one free by pliers or by a hammer and chisel. The weld should not break but the metal should tear in the strip beside the weld. |

## LESSON F

### Burning Holes

| | |
|---|---|
| **Material** | Scrap plate ½ in. thick. Supported as for Lesson A. |
| Electrode | ½-in. carbon. |
| Current | 300 amperes. |
| Position of electrode | Perpendicular to plate. |
| **Requirements** | ½-in. diameter holes. |
| **Procedure** | Hold electrode stationary, directing the arc at the point where the hole is to be made. When the heat first penetrates through the plate and the molten metal begins to run off, take the electrode away. As the metal cools off somewhat, repeat the operation and enlarge the hole to the desired size. Increase the size of the holes to 1 in. and then to 2 in. in diameter. |
| **Inspection** | Inspect for smoothness of the edges and for dimensions at each stage. Check for location of the holes particularly after enlargement to see that the removal of this additional metal has been uniform all around the edge. If this is not done properly the center of the enlarged holes will be different from the original center. |

When the welder has successfully completed the above series of exercises it must not be supposed that he can be considered an expert until he has had some experience with actual production work. It may be truthfully said that mere expertness or deftness of manipulation does not insure success as there are many problems of expansion and contraction and the setup of the job which arise and which must be solved or failure will result. A number of applications of arc welding are illustrated and described in Part III in order to help the operator realize that successful arc welding is not necessarily a mere mechanical manipulation, but really requires some common sense and ingenuity.

# PART III

# SOME APPLICATIONS OF ARC WELDING

## SYMBOLS AND DEFINITIONS

### Position of Work

There are three general positions of the work—flat, vertical and inclined. Flat indicates that the surface on which the weld is made is horizontal; vertical that it is vertical, and inclined indicates an angle, not a right angle, to the horizontal. When inclined the angle between the horizontal and the surface to be welded is usually specified.

### Position of Weld

There are four general positions of weld. (See Fig. 68.)

### FLAT

SYMBOL F

A flat position is one in which the welding material is applied in a generally downward direction.

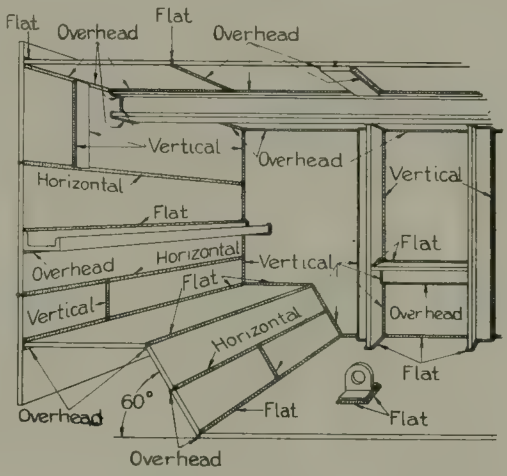


Fig. 68. EXAMPLES OF VARIOUS POSITIONS OF WELD

### HORIZONTAL

SYMBOL H

A horizontal position is one in which the welding material is applied to a seam or opening in a plate, the plane of which is vertical or inclined 45 deg. or less to the vertical, and the line of weld is horizontal. The electrode in this case is held in a horizontal position or the welding end is inclined slightly downward.

### VERTICAL

SYMBOL V

A vertical position is one in which the welding material is applied to a vertical surface or one inclined 45 deg. or less to the vertical, so that the line of weld is vertical or inclined 45 deg. or less to the vertical. The electrode in this case is held horizontal or the welding end is inclined slightly downward.

### OVERHEAD

SYMBOL O

An overhead position is one in which the welding material is applied from the underside of any member whose plane is such that it necessitates the electrode being held with its welding end upward.

## Nomenclature

Various systems of nomenclature are used to denote the design, type, position, etc. of welds used in construction. The symbols used in the following table have the advantage that the appearance of the symbol indicates the desired factor and that no arbitrary symbols must be memorized.

(See Fig. 69.)

### INSTRUCTION CHART WITH STANDARD SYMBOLS

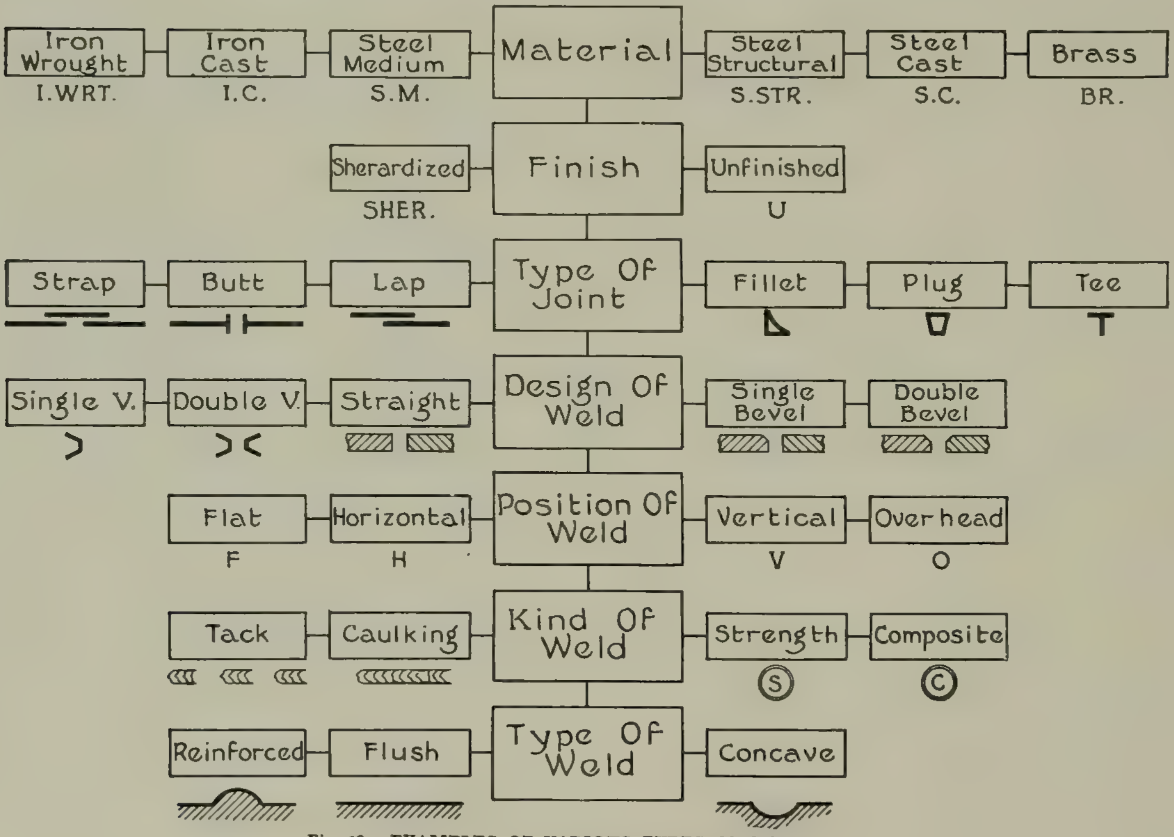


Fig. 69. EXAMPLES OF VARIOUS TYPES OF WELDS

## Type of Joint

STRAP

Symbol (See Fig. 69)

See Parts Nos. 37 and 40. Figs. 74 and 75

STRAP weld is one in which the seam of two adjoining plates or surfaces is reinforced by any form or shape to add strength and stability to the joint or plate. In this form of weld the seam can only be welded from the side of the work opposite the reinforcement, and the reinforcement of whatever shape must be welded from the side of work to which the reinforcement is applied.

### BUTT

Symbol (See Fig. 69)

See Parts Nos. 1, 3, 9, and 38. Figs. 71, 72, and 74

BUTT weld is one in which two plates or surfaces are brought together edge to edge and welded along the seam thus formed. The two plates when so welded form a flat surface or corner.

### LAP

Symbol (See Fig. 69)

See Parts Nos. 4, 5, 10, and 47. Figs. 71, 72, and 75

LAP weld is one in which the edges of two plates are set one above the other, and the welding material so applied as to bind the edge of one plate to the face of the other plate. In this form of weld the seam or lap forms a raised surface along its entire length.

### FILLET

Symbol (See Fig. 69)

See Parts Nos. 46 and 47. Fig. 75

FILLET weld is one in which some fixture or member is welded to the face of a plate, by welding along the edge of the fixture or member. The welding material is applied in the corner thus formed and finished at an angle of 45 deg. or less to the plate.

### PLUG

Symbol (See Fig. 69)

See Parts Nos. 43 and 44. Fig. 75

PLUG weld is one used to connect the metals by welding through a hole in either one plate or both plates. Also used for filling a bolt hole or fastening fixtures to the face of a plate by drilling a countersunk hole through the fixture, and applying the welding material through this hole thereby fastening the fixture to the plate.

### TEE

Symbol (See Fig. 69)

See Parts Nos. 39 and 45. Figs. 74 and 75

TEE weld is one where a plate is welded perpendicularly to another, and can only be used where it is possible to work from both sides of the perpendicular plate. Also used for welding a rod in vertical position to a flat surface, as the rung of a ladder, or a pipe welded perpendicularly to a plate.

## Design of Weld

### SINGLE "V"

Symbol (See Fig. 69)

See Part No. 39. Fig. 74

SINGLE "V" is a term applied to the "edge finish" of a plate when this edge is beveled on "both" sides to an angle of not less than 45 deg., and is to be used when the "V" side of the plate is to be a maximum "strength" weld with the plate setting vertically to the face of an adjoining member.

### DOUBLE "V"

Symbol (See Fig. 69)

See Parts Nos. 3 and 24. Figs. 71 and 73

DOUBLE "V" is a term applied to the "edge finish" of two adjoining plates when the adjoining edges of both plates are beveled on "both" sides to an angle not less than 30 deg. This is to be used when the two plates are to be "butted" together along these two edges for a maximum "strength" weld.

### STRAIGHT

Symbol (See Fig. 69)

See Parts Nos. 1, 9, and 41. Figs. 71, 72, and 75

STRAIGHT is a term applied to the "edge finish" of a plate, when this edge is left in its crude and sheared state.

### SINGLE BEVEL

Symbol (See Fig. 69)

See Parts Nos. 13, 27, and 42. Figs. 72, 73, and 75

SINGLE BEVEL is a term applied to the "edge finish" of a plate when this edge is beveled on "one" side only, to an angle of not less than 30 deg. This is used for "strength" welding, when the electrode can be applied from "one" side of the plate only, or where it is impossible to finish the adjoining welding surface.

### DOUBLE BEVEL

Symbol (See Fig. 69)

See Parts Nos. 2, 25, and 40. Figs. 71, 73, and 75

DOUBLE BEVEL is a term applied to the "edge finish" of two adjoining plates, when the adjoining edge of both plates are beveled on "one" side only to an angle of not less than 30 deg.

Note.—In the trade application the "double bevel" is ordinarily called "single V."

## Kind of Weld

### TACK

Symbol (See Fig. 69)

See Fig. 70

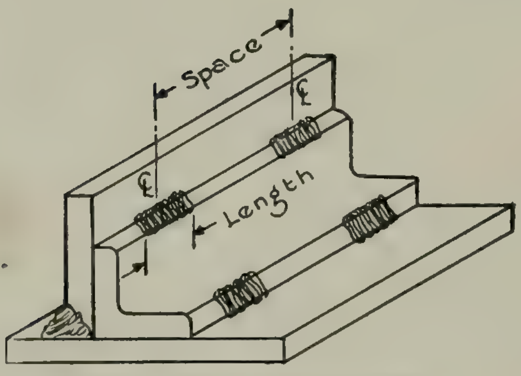
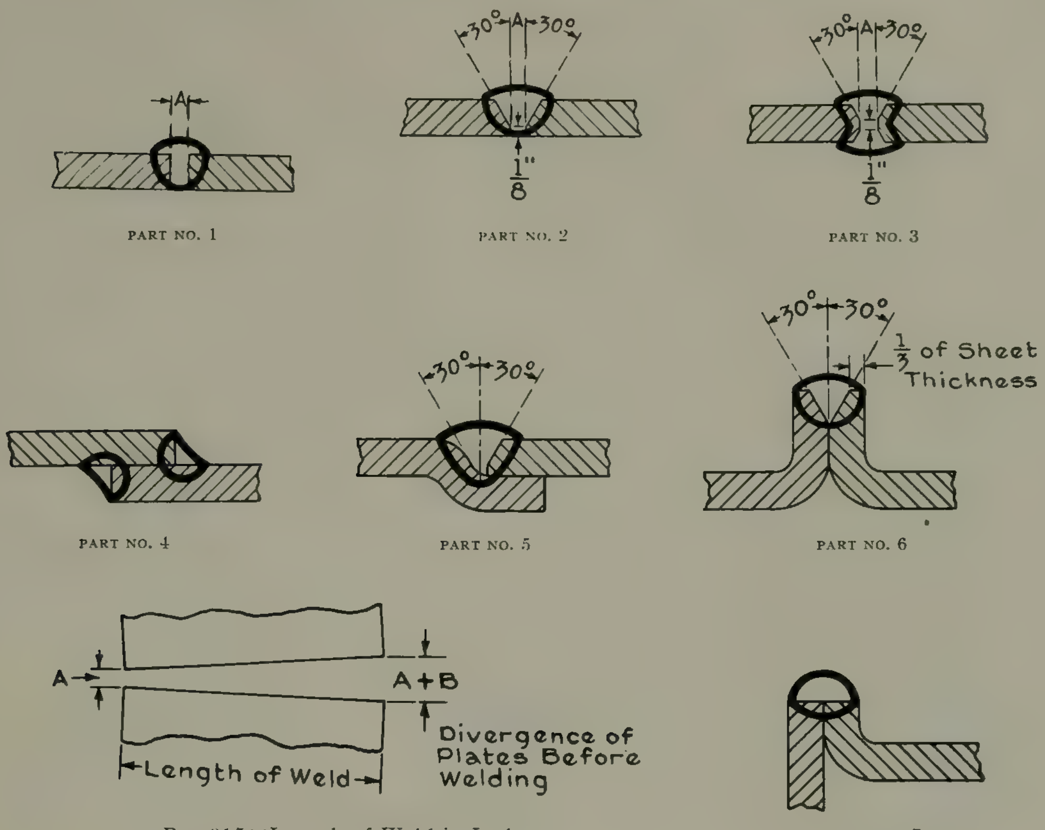


Fig. 70. EXAMPLE OF TACK WELD

A TACK weld is one in which the welding material is applied in small sections to hold two edges together, and should always be specified by giving the "space" from center to center of weld and the "length" of the weld itself. It is not necessary to consider the design of the weld. A tack weld is also used for temporarily holding in place material that is to be solidly welded, until the proper alignment and position is obtained. In this case neither the length, space, nor design of weld need be specified.



B = .015 × Length of Weld in Inches

Fig. 71. EXAMPLES OF VARIOUS TYPES OF WELDS

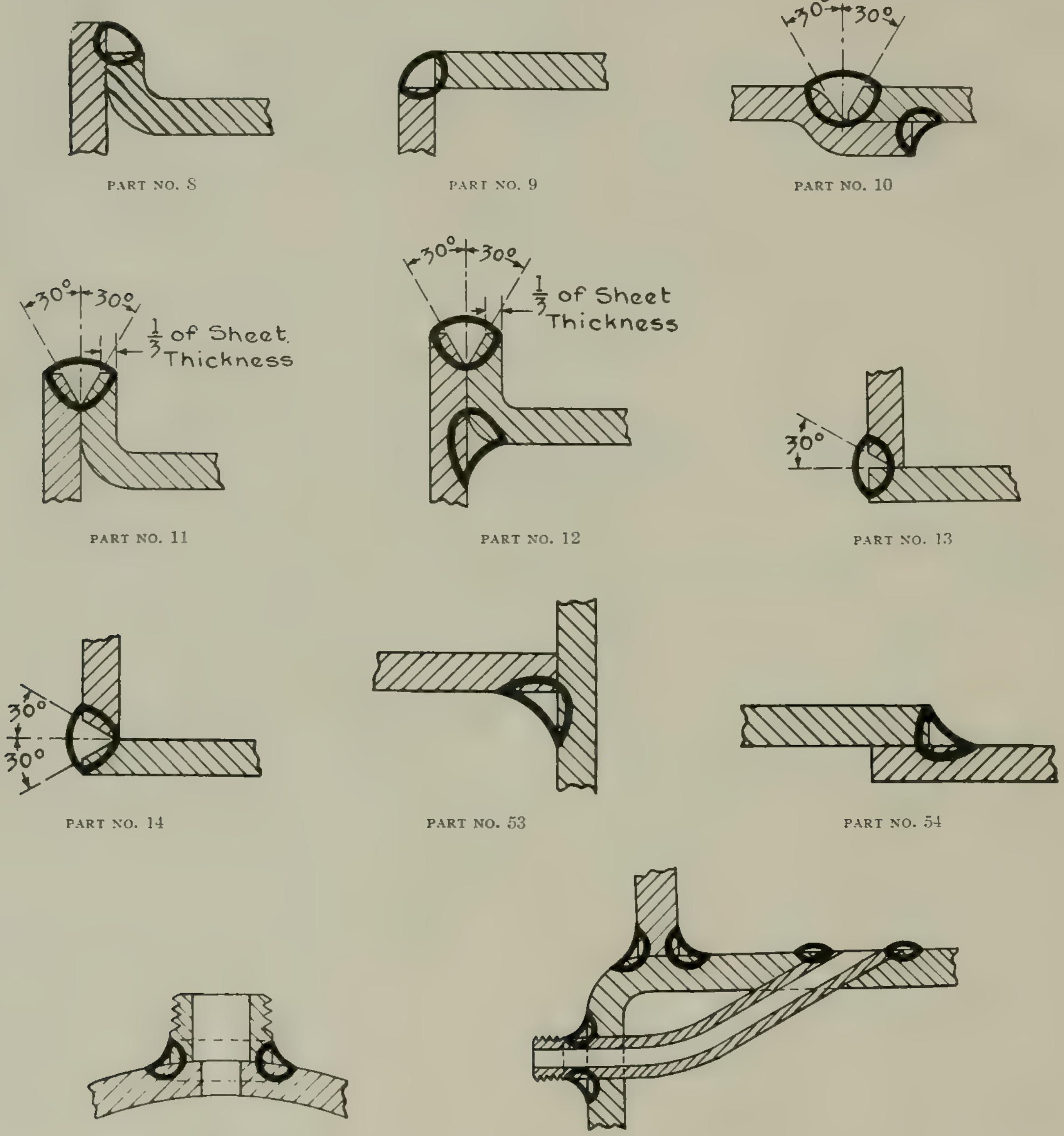
| Part No. | DIMENSIONS IN INCHES | |
|---|---|---|
| | Thickness of Plate | Space A |
| 1 | 1/32 to 1/16 | 0 |
| 1 | Above 1/16 to 1/8 | 0 to 1/32 |
| 1 | Above 1/8 to 1/4 | 1/32 to 1/8 |
| 2 | Above 1/4 | 0 |
| 3 | Above 1/2 | 0 |

## CAULKING

Symbol (See Fig 69)

See Parts 22, 46, and 47. Figs. 73 and 75

A CAULKING weld is one in which the density of the deposited metal used to close the seam or opening is such that no leakage appears under a water, oil or air pressure test of 25 lb. per sq. in. Neither the ultimate strength nor the design of the weld is of any particular importance.



PART NO. 8 PART NO. 9 PART NO. 10

PART NO. 11 PART NO. 12 PART NO. 13

PART NO. 14 PART NO. 53 PART NO. 54

PART NO. 19 PART NO. 20

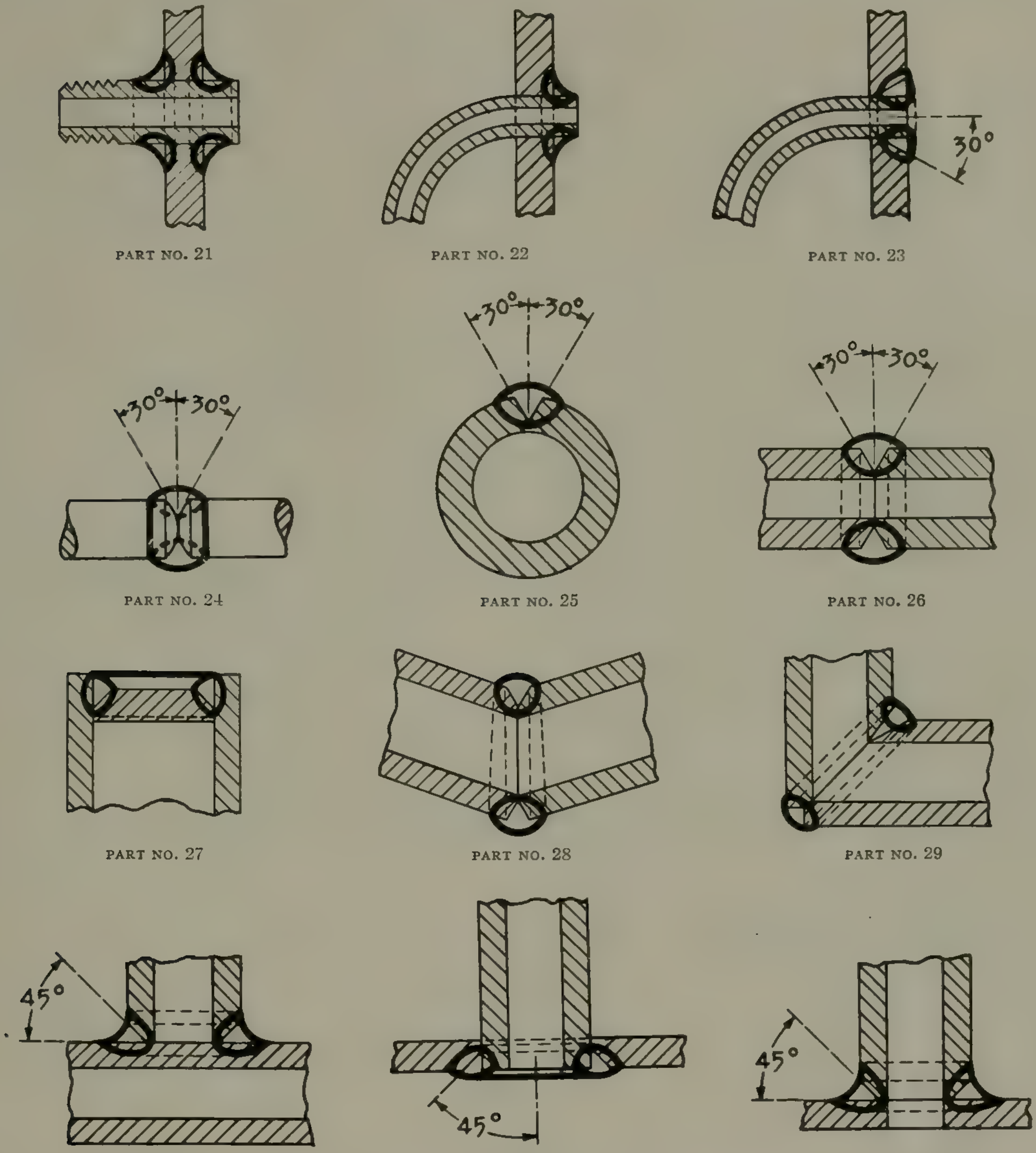
Fig. 72. EXAMPLES OF VARIOUS TYPES OF WELDS

## STRENGTH

Symbol (See Fig. 69)

See Parts Nos. 3, 24, 37, and 39. Figs. 71, 73, and 74

A STRENGTH weld is one in which the sectional area of the weld is sufficient to give the joint a tensile strength of at least 80 per cent of the strength of the surrounding material and the welder must attempt to attain 100 per cent. The welding material may be applied in any number of layers. The density of the deposited metal is not of vital importance.



PART NO. 21 PART NO. 22 PART NO. 23

PART NO. 24 PART NO. 25 PART NO. 26

PART NO. 27 PART NO. 28 PART NO. 29

PART NO. 30 PART NO. 31 PART NO. 32

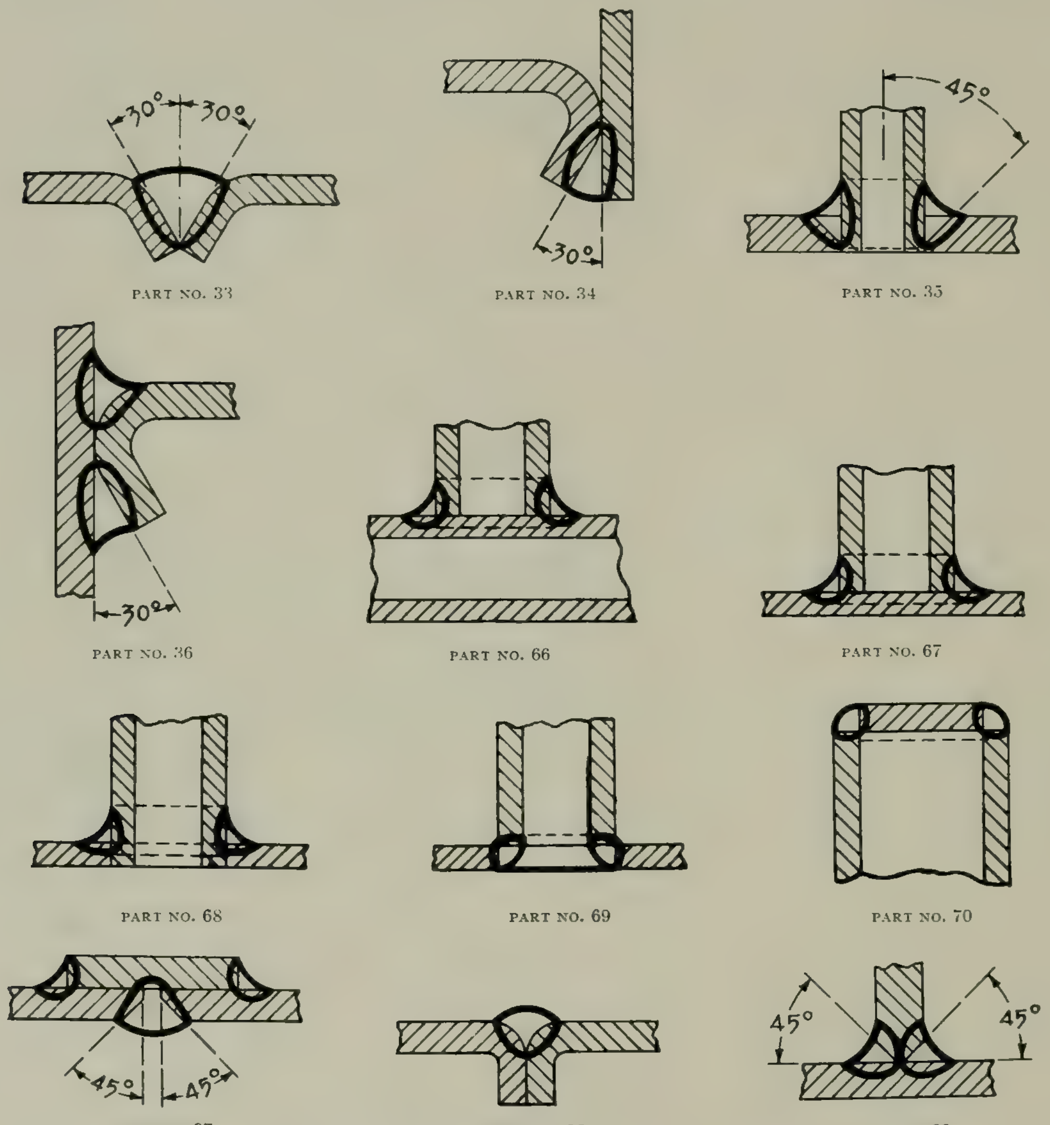
Fig. 73. EXAMPLES OF VARIOUS TYPES OF WELDS

## COMPOSITE

Symbol (See Fig. 69)

See Parts Nos. 3, 4, and 37. Figs. 71 and 74

A COMPOSITE weld is one in which both the strength and density are of the most vital importance. The STRENGTH must be at least as specified for a "strength weld" and the density must meet the requirements of a "caulking weld" both as above defined.



PART NO. 33 PART NO. 34 PART NO. 35

PART NO. 36 PART NO. 66 PART NO. 67

PART NO. 68 PART NO. 69 PART NO. 70

PART NO. 37 PART NO. 38 PART NO. 39

Fig. 74. EXAMPLES OF VARIOUS TYPES OF WELDS

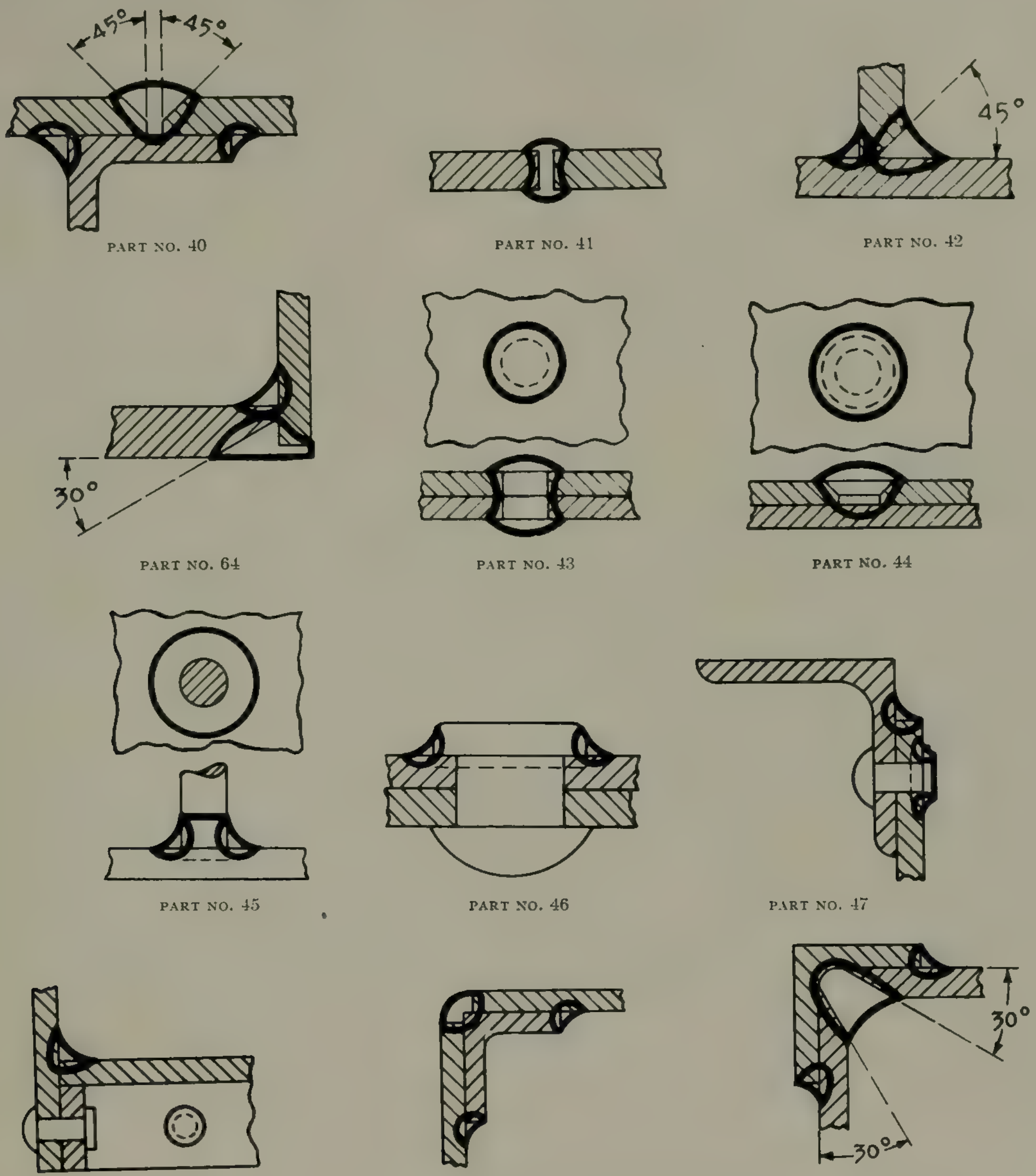
**Type of Weld**

## REINFORCED

Symbol (See Fig. 69)

See Parts Nos. 3, 4, 9, and 24. Figs. 71, 72, and 73

REINFORCED is a term applied to a weld when the top layer of the welding material is built up above the plane of the surrounding material. When used for a 90 deg. corner, the top of final layer should project above a plane of 45 deg. to the adjoining material. This type is chiefly used in a "strength" or "composite" weld for the purpose of obtaining the maximum strength.



PART NO. 40 PART NO. 41 PART NO. 42

PART NO. 64 PART NO. 43 PART NO. 44

PART NO. 45 PART NO. 46 PART NO. 47

PART NO. 48 PART NO. 49 PART NO. 50

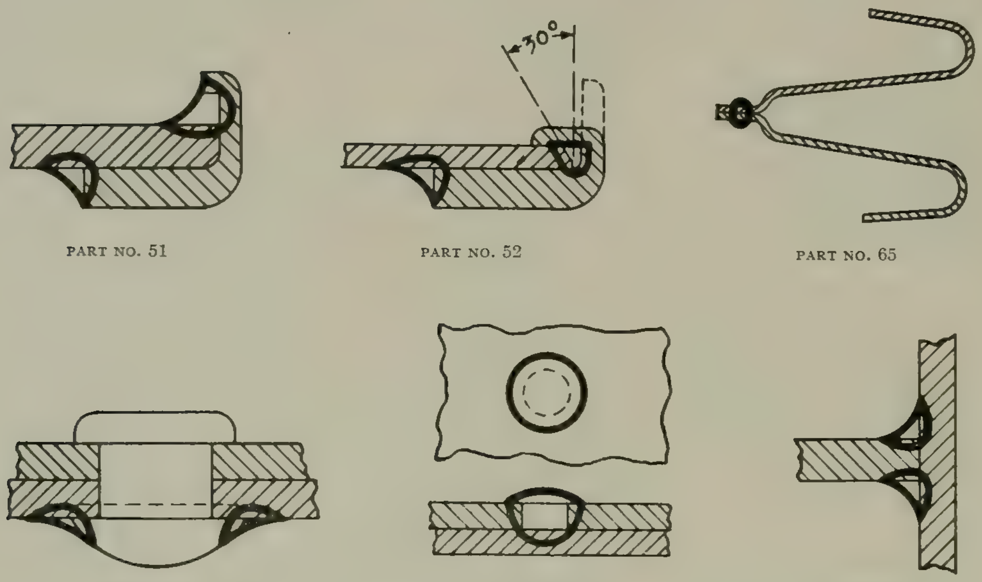
**Fig. 75. EXAMPLES OF VARIOUS TYPES OF WELDS**

## FLUSH

Symbol (See Fig. 69)

See Parts Nos. 1, 5, and 8. Figs. 71 and 72

FLUSH is a term applied to a weld when the top layer is finished perfectly flat, or in the same plane as the adjoining material, or at an angle of 45 deg. when used to connect two surfaces at an angle to each other. This type of a weld is to be used where a maximum tensile strength is not important.



PART NO. 51

PART NO. 52

PART NO. 65

PART NO. 71

PART NO. 72

PART NO. 73

**Fig. 76.** EXAMPLES OF VARIOUS TYPES OF WELDS

## CONCAVE

Symbol (See Fig. 69)

See Parts Nos. 41 and 51. Figs. 75 and 76

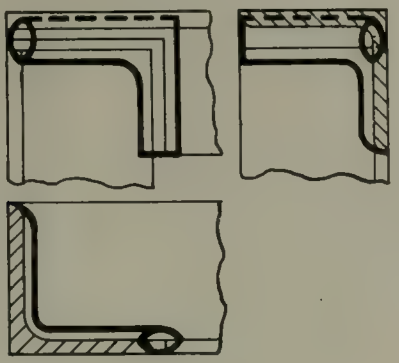
CONCAVE is a term applied to a weld when the top layer finishes below the plane of the surrounding material, or beneath a plane of 45 deg. at an angular connection. To be used as a weld of no further importance than filling in a seam or opening, or for strictly caulking purposes, when it is found that a minimum amount of welding material will suffice to sustain a specified pounds per square inch pressure without leakage.

## STRUCTURAL ANGLE WELDS

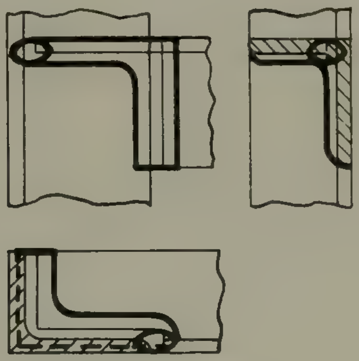
Parts Nos. 59, 60, 61, 62, and 63. Fig. 77

One great advantage afforded by arc welding is that of eliminating lapping of members. By cutting away the projecting legs of angles where they join in such a way that they fit together in the same plane as shown in Fig. 77 the weld can be made as shown and the overlapping of metal is avoided. Joints of this character are very desirable where a sheet steel casing or covering is to be placed over the outside. There need be no crimping or fitting as the sheathing will lie flat on the frame.

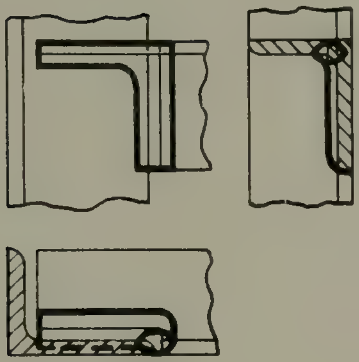
This type of weld also has another advantage of strength because it lies in the same plane as the stress which is transmitted to it from the angle. In this way there is less chance for bending stresses to be introduced into the weld. The assembly by use of jigs is simpler and the welds are easy to make.



PART NO. 59



PART NO. 60



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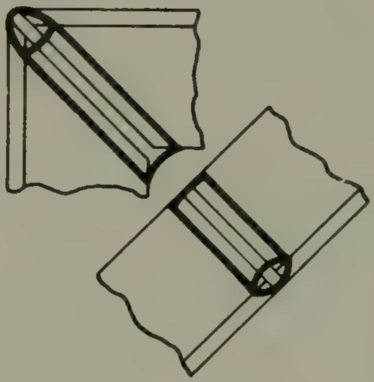

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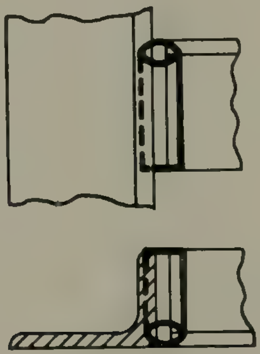


PART NO. 63

Fig. 77. EXAMPLES OF VARIOUS TYPES OF WELDS ON STRUCTURAL ANGLES

## PRINCIPAL METALS ENCOUNTERED IN ARC WELDING

### General Characteristics and Composition

**Ferrous Metals**

The term steel is applied to a metal consisting principally of iron but containing carbon to the amount of from 0.2 per cent to 2.0 per cent by weight. Where the carbon content is below this range we have the irons—wrought iron, Swedish and Norway iron, Ingot iron, etc. Where the carbon content is from 1½ to 2½ per cent the metal is termed semi-steel and from 2½ to 4 per cent carbon produces cast iron.

| Name | Amount of Distinguishing Alloying Material | Characteristics | Weldability |
|---|---|---|---|
| **Steels** | | | |
| High Carbon<br>Carbon—Iron<br>Cast Iron | 2½ to 4% Carbon | Weak in tension. Brittle. No ductility. | Difficult |
| Tool Steel | 0.90 to 1.65% Carbon | Can be machined very hard. High tensile strength. Ductility low. | Practically Impossible |
| Spring Steel | 0.75 to 1.0% Carbon | Can be hardened. High tensile strength. Ductility increased. Will stand bending. | Unsatisfactory |
| Medium Carbon<br>Casting Steel | 0.20 to 0.45% Carbon | Will harden somewhat. Tensile strength less than above. Ductile and malleable. | Welding Satisfactory |
| Forging | Some castings up to 0.55. | | |
| Sheet Steel<br>Steel Plate and Structural Steel | 0.15 to 0.35% Carbon | Will not harden much. Tensile strength. Ductile and malleable. | Welding Satisfactory |
| Low Carbon<br>Wrought Iron<br>NorwayIron,etc<br>Ingot Iron | 0.03 to 0.08 Carbon | Soft—Ductile | Welding Satisfactory |
| **Alloy Steels** | | | |
| Nickel Steel | Approx. 3.5% Nickel | Resistant to shock. Can be hardened. | Weldable |
| | 0.15 to 0.40% Carbon | Shafts—Gears. | Amount of carbon determines weldability. Below 0.35% C O.K. |
| Chromium Steel | 0.65 to 1.30% Chrom. | Very hard. | |
| | 0.15 to 1.20% Carbon | Gears—Ball bearing races, etc. | |
| Chrome Nickel Steel | 0.15 to 0.55% Carbon<br>1.0 to 3.5% Nickel<br>0.45 to 1.75% Chrom. | Combination of two simple alloys | Welding Difficult |
| Manganese Steel | 1.0 to 1.3% Carbon<br>11 to 14% Manganese | Strong. Tough---cannot be machined. Hard — cannot be softened. Railway track work—crusher parts. | Weldable |
| | 0.35 to 75% Carbon<br>0.60 to 1.15 Manganese | Steel rails. | Weldable |
| Vanadium | Used in small amounts up to 0.25% in combination with other alloys. Greatly increases resistance to fatigue. | | |
| High Speed Steel | Up to 1% Carbon<br>Up to 20% Tungsten<br>Up to 4% Cr.<br>Up to 1% Va. | Hard—strong. | Weldable |

**Non-Ferrous Metals**

Copper—
Brass—Alloy of Copper and Zinc with other metals.
Bronze—Alloy of Copper and Tin with other metals.
Monel Metal—Alloy of Nickel and Copper.
Aluminum—

Ferrous metals containing over 0.25 per cent of carbon are very susceptible to heat treatment. If such metals are heated to the critical temperature, which varies with the composition but is in general a red heat or above, and then rapidly cooled, the carbon remains combined with the iron and results in a hard brittle metal. By again heating, the carbon is progressively released from this form and various characteristics in the metal may be obtained. By heating the metal to the critical temperature and allowing it to cool **slowly,** the metal can be obtained in its softest, least brittle form.

In making a weld, a portion of the metal of the work is fused in order to be joined to the added metal. Usually the mass of the work is large compared to that of the weld and heat is rapidly conducted away, cooling the weld quickly. This tends to cause a hard brittle and weak zone in the work around the weld at the point where the metal has just reached the fusion temperature. This effect is greater as the carbon content of the work metal increases. Annealing after welding will practically eliminate this undesirable condition.

## CAST IRON WELDING

The welding of cast iron is attended with great uncertainty and while a great deal has been done toward the determination of proper methods and materials, the difficulties encountered render a cast iron weld doubtful in quality as compared to a weld of steel. A discussion of the subject in great detail is contained in the September, 1922, and November, 1922, Journal of the American Welding Society.

The weldability of this metal is largely dependent on the foreign materials present in the cast iron and the amount of each, on the previous heat treatment of the piece, and on the shape of the piece. The effect of this latter consideration will be discussed later under the subject of "Expansion and Contraction."

Cast iron contains carbon in amount usually from 3 to 4 per cent. When the metal is molten, the carbon is all dissolved in the iron as a chemical compound—Iron Carbide ($Fe_3$ C). If the iron is very rapidly cooled, a large portion of the carbon remains in this form and the result is White Iron, a hard brittle metal, which is hard to machine and, when broken, the fracture appears white, close grained and brilliant in luster.

If, on the other hand, the metal is allowed to cool and solidify slowly, most of the carbon separates out in the form of graphite flakes scattered throughout the metal. This metal is known as Gray Iron, which while brittle is easily machined. When broken the fracture is gray in color and the crystal structure is coarse, and the surface has little or no luster. The graphite in this metal will smudge the fingers or a sheet of paper.

White Iron can be converted to Gray Iron by annealing or by heating slowly to about 1600 deg. F. and cooling slowly.

Silicon is used in amounts up to 2.5 per cent to reduce the solubility of carbon in the iron. The effect of silicon therefore is to form gray iron. It also helps to increase the fluidity and to decrease the shrinkage.

Sulphur is undesirable since it increases the solubility of carbon in the iron, it makes the metal brittle when red hot (or red short), and it increases the tendency to form shrinkage, cracks and holes. This material is usually kept as low in quantity per cent as possible.

Manganese is used principally to combine with and eliminate the sulphur although it does tend to harden the metal also.

Phosphorus has three effects on the iron. It makes the metal brittle and weak, it lowers the melting point, and it increases the fluidity. Phosphorus is ordinarily kept low except in the case of thin intricate castings where great fluidity and low melting point are necessary to permit the iron to stay fluid long enough to flow to and fill all parts of the mold.

### Welding Cast Iron (Carbon Electrode)

Iron castings should generally be preheated before welding and annealed after welding Both the heating and cooling should be slow to avoid warping and the introduction of strains with possible fractures. If preheating is used, the weld should be made quickly while the work is hot. The edges of the weld should be prepared with either a double bevel or double "V," and the weld should be made in a flat position. It may be necessary to back up the weld. The use of a suitable flux is recommended although in some cases no flux is necessary. A good flux can be made of a mixture of equal parts of carbonate of soda and bicarbonate of soda. Washing soda is the name commonly given to a somewhat impure carbonate of soda, while bicarbonate of soda is ordinary baking soda. It is not necessary that either should be in a chemically pure state. The action of the carbonates is to combine with the oxygen in the slag, releasing the iron and allowing the oxygen to pass off in the form of carbon monoxide or carbon dioxide. It will be noticed that when a little flux is added to the molten iron under the arc, the surface of the metal becomes clear and mirror-like showing that the impurities have been "fluxed" out.

Direct the arc on the upper edges of the groove until they commence to melt and then melt down the bottom of the weld, adding a little flux. As this metal flows together gradually bring molten metal from the sides down into the groove. Then add metal from the filler rod until the metal is built up as high as desired. Advance along the weld and repeat this procedure. Care should be taken not to add too much metal at one time or in any other way permit metal to flow down the groove before the bottom has been melted down and the two edges joined. If metal merely runs down in this way, it will bridge over and cause a "cold shut."

### Filler Rod

The filler rod should preferably be a rod or stick of cast iron but in some cases steel may be used. Special cast iron rods high in silicon and low in manganese are found to be very good. Diameters of ¼ in. for small work and ½ in. for heavy work have been found satisfactory.

### Current

This is determined for each job by the experience of the welder. A maximum of 350 to 400 amperes is seldom exceeded. Too much heat causes the metal to run too fast to be controlled.

### Welding Cast Iron (Metallic Electrode)

Preheating and annealing are beneficial in connection with this type of weld but in many cases are dispensed with, due to the size of the casting making such treatment expensive or impossible. Sometimes the electrode is the same as that used for the welding of steel. With this electrode it is difficult to obtain good penetration, particularly on gray iron. This is aggravated by the formation of the hard zone around the weld which is an additional source of weakness.

The effect of shrinkage of the metal in the weld as it cools is to draw the two edges closer together. If the shape of the work is such that it cannot give, this shrinkage introduces strains in the work that must be counteracted. Generally a weld will fail in the cast iron just outside the weld. This is the hard zone previously described. If the weld is sufficiently reinforced, the shrinkage or contraction may cause a failure at some other point. Another consideration is the fact that the steel used in the electrode will contract about 50 per cent more than cast iron in cooling from the molten condition. This causes the deposited metal to tend to slip along the cast iron and sets up local strains with possible failure along the surface between these two metals.

The above conditions have to do with the strength of the weld but should be considered also for the effect on the machinability, as many castings have to be machined after welding. The hard zone referred to will either break a tool or cause it to jump and therefore must be eliminated if the weld is to be machined. Any of the welds may be ground if such a finish is satisfactory.

Other welds must be tight to steam, oil or water, etc. In such case no porosity can be permitted.

### Qualities Desired in a Cast Iron Weld

The qualities desired in any given weld are determined by the service to which it will be subjected and will consist of one or more of the three general qualities.

Strength
Machinability
Tightness

Strength in a cast iron weld may be increased by preheating and annealing, by eliminating the hard zone about the weld, and by eliminating strains due to contraction of the heated metal near the weld. These strains if remaining in the casting may be such as to add directly to the strains set up by the normal service and bring the total to a value beyond the strength of the casting.

### Studding

A cast iron weld may be strengthened by anchoring the deposited metal to the casting. Steel studs ¼ in. or larger in diameter should be screwed into holes drilled and tapped into the iron to a depth approximately equivalent to the diameter of the studs and located so they will be covered by the added metal when the weld is completed. (See Fig. 78 and 79.) The area of the steel studs should total from ¼ to ⅓ the total area of the weld and in this case the strength of the weld can be taken as the strength of the studs. This ratio is the ratio between the strength of the cast iron and steel so such a weld will develop the full strength of the cast iron section. The studs should project ⅛ to ¼ in. above the surface. A square groove chiseled along the sides of the weld has been recommended as a means of anchoring the weld so that the contraction of the added metal in drawing the edges together will be independent of the adhesion between the two metals.

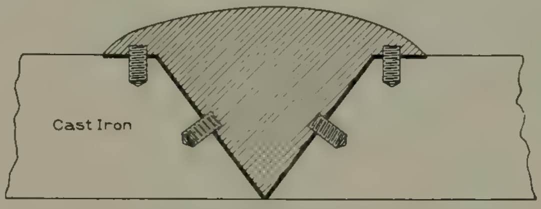


Fig. 78. CROSS SECTION OF STUDDED JOINTS ON THICK MATERIAL

In general, the welding of cast iron with the metallic electrode differs in procedure from the welding of steel. In welding cast iron a layer of metal is first deposited over the surface of the cast iron by laying a succession of beads side by side until the surface of the iron is entirely covered. This is done whether studs are used or not. After the surface is covered with this layer of steel, the weld is made from one side to another just as though the casting were of steel. When studs are used care should be taken to thoroughly fuse the studs into the deposited metal.

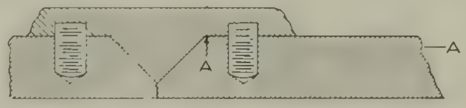


Fig. 79. CROSS SECTION OF STUDDED JOINT ON THIN MATERIAL

Strength and tightness in a cast iron weld may be obtained by lightly peening the deposit with a hammer when changing electrodes. This peening stretches the cooling metal and relieves internal stresses which always exist due to contraction in the deposited metal. Careful annealing will usually relieve these stresses and also prevent brittleness which generally causes a weak weld. In most cases a cast iron weld properly annealed will be stronger than the original base metal was before annealing. In general, the strength of the weld may be made equal to the strength of the cast iron unless there are some limitations imposed on the method of making the weld.

A weld may be made machinable by proper annealing. In many cases the method shown in Fig. 80 has been used when one side only of the weld is to be machined, and annealing for this purpose cannot be resorted to. In many cases where machinability and tightness are of prime importance special alloy electrodes are used.

Tightness in a weld will depend on the continuity of the bond between the cast iron and the first layer of deposited metal. Leaks usually occur through this zone, particularly when studs are used. Care in making the weld and avoiding any signs of porosity are the only means of making a tight weld. Peening will close openings through the deposited metal but will only cause trouble if attempted along the edge of the weld and against the cast iron. Sal ammoniac will sometimes seal small leaks of this nature.

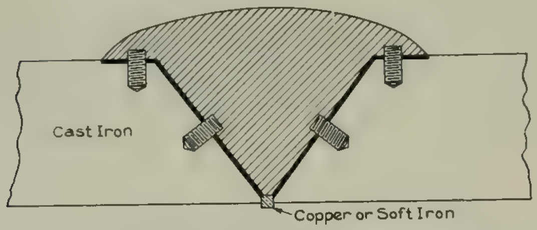


Fig. 80. CROSS SECTION OF JOINT SHOWING INSERTION OF COPPER STRIP

**Special Electrodes**

Commercial **phosphor bronze** wire has been used to obtain machinable welds.

**Nickel and manganese-nickel** electrodes have also been used for this purpose and while to a great extent machinable it is still possible to detect a slight hard zone. Further, the deposited metal has a tendency to sponginess and is low in strength, and therefore not suitable for joining parts. This material is much used for plugging small sand holes or blow holes in the bore of gasoline engine cylinders. The arc is struck at the bottom of the hole and there anchors the metal. Metal runs against the sides of the hole but the arc is not directed there in order not to heat the iron at that point sufficiently to cause the formation of a hard zone. After the hole is filled and metal built up slightly, the metal is peened down and the surface machined. The current should be as low as possible and the operator must use care in fusing the electrode.

In joining parts with a weld of more than one layer it is possible to use these nickel electrodes for the first or the last layer and depend on the inside layers for strength.

**Monel metal** electrodes have been used in this way as have electrodes of other copper-nickel alloys.

Surface layers of nickel alloy electrodes, as used for machinability, make it possible to peen the metal and close leaks with more or less success.

## WELDING MANGANESE STEEL

### General Properties

Steel with a manganese content slightly over 1 per cent is hard and brittle, and this brittleness increases with an increase of the manganese content until with a percentage of from 4 to 5½ the steel can be powdered under the hammer. These properties do not increase, however, with an increase of manganese above this mount. At a manganese content of about 7 per cent, an entirely new set of properties begin to appear. These are well marked at 10 per cent and reach a maximum at 12 to 15 per cent of manganese.

Manganese steel usually contains about 12 to 13 per cent of manganese and 1.25 to 2 per cent of carbon. With this amount of manganese, the strength and ductility of the steel reaches its maximum. In order to secure a ductile material, however, manganese steel must be quenched from a temperature of more than 1000 deg. C. (1832 deg. F.). The steel which was very brittle before this treatment is afterward as ductile as soft carbon steel or wrought iron, while its tensile strength is considerably greater. The hardness is so great that it is not commercially practicable to machine it and there is no method known of making it softer.

The beneficial effect of sudden cooling, as well as the good physical qualities which may be obtained, is reassuring especially since this condition is greatly facilitated by arc welding, which permits cooling as frequently as necessary with but little interference with the welding operation.

To illustrate the effect of quenching of cast manganese steel the following figures are given:

CHEMICAL COMPOSITION (APPROXIMATELY)

| | |
|---|---|
| Carbon | 1.25% |
| Silicon | 0.30% |
| Manganese | 12.30% |
| Sulphur | under 0.02% |
| Phosphorus | 0.8% |

**Average of Physical Tests of Above Material**

| | |
|---|---|
| Tensile Strength, lb. per sq. in. | 108,460 |
| Elongation, per cent | 34 |

**Average of Tests on Quenched Material**

| | |
|---|---|
| Tensile Strength, lb. per sq. in. | 157,250 |
| Elongation, per cent | 53.3 |

The proper temperature from which arc deposited manganese steel should be quenched is a point which has been questioned by some investigators. Some tests have shown a falling off in tensile properties and elongation on quenching from a temperature in excess of 1000 deg. C. The following test data tend to confirm this belief. The duration of heating, however, has almost as important an effect as the temperature itself.

**Specimens Held One Hour and Quenched**

| Temperature | Elongation | Tensile Strength Lb. per Sq. In. |
|---|---|---|
| 1800°F. (1000°C.) | 56.5 | 133,400 |
| 2100°F. (1165°C.) | 35.7 | 93,200 |
| **Specimens Held Five Minutes and Quenched** | | |
| 1800°F. (1000°C.) | 56.4 | 142,450 |
| 2066°F. (1150°C.) | 34.4 | 124,780 |

In this case the higher temperature did not affect the elongation and tensile strength nearly as much when held for a few minutes as when heated at the higher temperature for a period of one hour. The short time at the maximum temperature apparently did not give the steel quite enough time to come fully to equilibrium, and, as a result, the structure of the test piece was not greatly altered from that which existed prior to the heat treatment.

Commercial welding of manganese steel may be accomplished by the metallic arc process with coated manganese electrode and by water toughening the added metal. The metallic arc form of autogenous welding is particularly adapted to the welding of metal of this character, since it is about the only form of autogenous welding which permits, without difficulty, the water toughening treatment of the added metal.

## Electrode Material

The chemical composition and physical properties of the manganese electrodes ordinarily used are as follows:

**Chemical Composition**

| | |
|---|---|
| Manganese | 11 to 14% |
| Carbon | 1.00 to 1.30% |
| Silicon | 0.10 to 0.20% |
| Phosphorus | 0.05 to 0.09% |
| Sulphur | 0.01 to 0.03% |

**Tests of Rolled and Forged Specimens**

| | |
|---|---|
| Ultimate Tensile Strength, lb. sq. in. | 140,000 to 160,000 |
| Elongation per cent | 35 to 50 |
| Shearing Strength, lb. sq. in. | 100,000 to 110,000 |

**Tests of Cold Drawn Wire**

(⅛-in. Wire not heat treated after last draw)

| | |
|---|---|
| Ultimate Tensile Strength, lb. sq. in. | 193,000 |
| Elongation, per cent | 20 |

The use of protective coating of the proper character on the electrode is necessary to prevent vaporization of the manganese and carbon constituents due to combustion which is supported by the oxygen of the atmosphere. The function of the coating is to envelop the metal in fusion with a thin slag film, confine the arc gases and exclude to a great extent the atmospheric gases.

**Manipulation**

In practice it is found that reversed polarity gives a better welding characteristic and that the loss of carbon and manganese is less. For this reason, where direct current is used the electrode is made positive and the work piece negative.

When welding with manganese steel on either manganese or high carbon steel, it is found advisable to form a rather wide deposit approximately double the width of that obtained by drawing the electrode along a straight line, i.e., by use of a spread bead instead of a narrow bead. By this manipulation the deposited metal is kept in a molten condition for a slightly longer period, allowing time for the escape of any gas which may be included in the deposit, and thus preventing the formation of blow holes.

To prevent the formation of a brittle structure, the work piece including the weld area is kept cool by quenching with cold water immediately after each electrode is used and more often on light sections where the part tends to become too hot, or at any time the welding is interrupted. As the object of this procedure is to constantly exercise a quenching action on the deposited metal, unless the water cooling is frequent, the rate of cooling will be variable with a corresponding difference in physical character of the added metal.

In track work the cooling is accomplished by directing a small stream of water directly on the previously deposited metal until the heat retained in the part will just dry or vaporize the water. Before the welding is again continued, the surface where the arc is to be established must be dry, otherwise difficulty will be experienced in establishing the arc. It is desirable to wipe the surface dry with a piece of waste when necessary before starting the arc.

When building up track parts, such as frogs and crossings, it is advisable to apply each deposit diagonally to the direction of the traffic, and terminate the weld on a bias, the point of the bias being on the flange side of rail. This procedure is thought to be the best practice in order to minimize the effect of contraction and possible structural disturbance of the parent metal from the heat of the welding operation.

The sizes of the electrode most generally used for track work are $\frac{3}{16}$ in. and $\frac{1}{4}$ in. The $\frac{3}{16}$ in. size seems better adapted for general work, especially where 200 ampere welding units are used.

The arc length should be maintained as short as consistent for a uniform flow of metal about $\frac{3}{16}$ in. If with this arc length the metal does not flow smoothly, it is likely that the arc current value is too low.

To avoid roughness or overrunning of the added metal at the flange side of the rail and on both sides of points, a piece of fire brick or carbon block should be set in the flange groove so as to project up and form a wall for the added metal to flow against. The use of fire brick or carbon blocks for making forms at the extreme points and edges will greatly facilitate the welding and result in better and more uniform work.

Where welding is done out in the open, a small shield 8 or 10 in. high should be set up to shield the arc from the eyes of observers and from air drafts, especially on windy days. Unless the arc is protected from air drafts, welding will be very difficult and an unnecessary loss of carbon and manganese will result.

### Finishing

If desired, the weld may be finished by grinding to allow a smooth approach for the wheel and prevent impact at the junction of the weld. However, if pains are taken by the operator to make as smooth a weld as possible, grinding is not considered absolutely necessary. The natural flowing characteristic of manganese steel will in a short time result in the weld becoming quite smooth. The operator should not only endeavor to make a smooth weld but should also use care to see that the top of the weld is level with other parts of the track work, being particular to avoid sharp humps or low spots.

The records of a number of applications which have been made in both steam railroad and street railway tracks, seem to have little doubt as to the commercial success of arc welding manganese steel. On a service cost basis, the service already obtained from welded crossings is such as to insure the permanency of the process.

### Uses of Manganese Steel

Manganese steel is used chiefly for the jaws and wearing parts of rock crushing machinery and similar apparatus, for railroad frogs and crossings, for railroad rails and curves and mine car wheels. Its life in these classes of service is very many times that of all other kinds of steel, because it is not only extremely hard, but is also without brittleness. The uses of manganese steel are limited chiefly because the metal must ordinarily be formed by casting, since machining and cutting are practically out of the question, and forging is difficult. For structural work the advantage of its high combination of strength and ductility are somewhat offset by its low elastic limit which is only about 35 per cent of its ultimate tensile strength. One peculiarity of manganese steel is that when it yields to tensile stresses it is elongated more uniformly over its whole length than carbon steel, which suffers its greatest elongation near the point of final rupture where a certain amount of "necking" takes place. It is, therefore, easy to see that the success of a manganese steel weld depends considerably upon the heat treatment of the deposited manganese steel which must be not only ductile, but also very resistant to abrasive action.

NOTE.—The test results and discussion contained in the foregoing paragraphs are taken from a paper entitled "Metallic Arc Welding of Manganese Steel," presented by H. R. Pennington before the Chicago Section of the American Welding Society and printed in the *Railway Electrical Engineer* for December, 1921.

## STRUCTURAL STEEL WELDING

### Test Data

The application of arc welding to steel structures opens up a large field for the use of this process. Several examples of steel structures having been constructed exclusively by the use of welding for joining the parts together might be mentioned, but if the reader is sufficiently interested, he should refer to the February, 1923, issue of the Journal of the American Welding Society for further details.

It appears that many joints in an arc welded steel structure will necessarily be so fabricated that the stress which must be carried safely by the arc deposited metal will be a shearing stress. (See Figs. 81 and 82.) With this idea in mind some tests have been made using a type of test specimen which is shown in Fig. 83. The stress is applied to the weld in a direction parallel to the axis of the weld. The plates used were ordinary structural steel which presents no difficulty in welding. Various sizes of plate and lengths of weld were used in order to determine the effects of different sizes of joint. The fractures of the welds

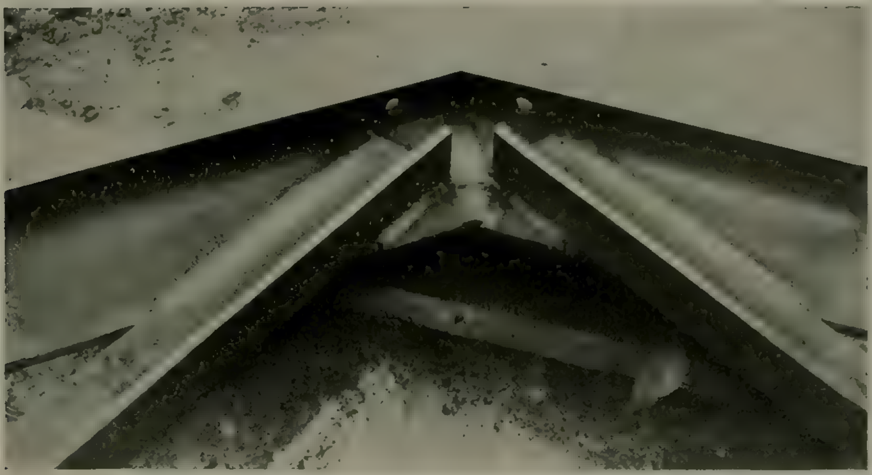


Fig. 81. PEAK OF ELECTRICALLY WELDED ROOF TRUSS

occurred approximately along a line indicated by X in Fig. 84, and the average shearing strength obtained was about 36,000 lbs. per sq. in. Using this figure with a factor of safety of 4, the table Series I on page 87 gives the safe strength per linear inch of bead for joints which are required to stand a pure shearing stress, applied as shown in Fig. 84.

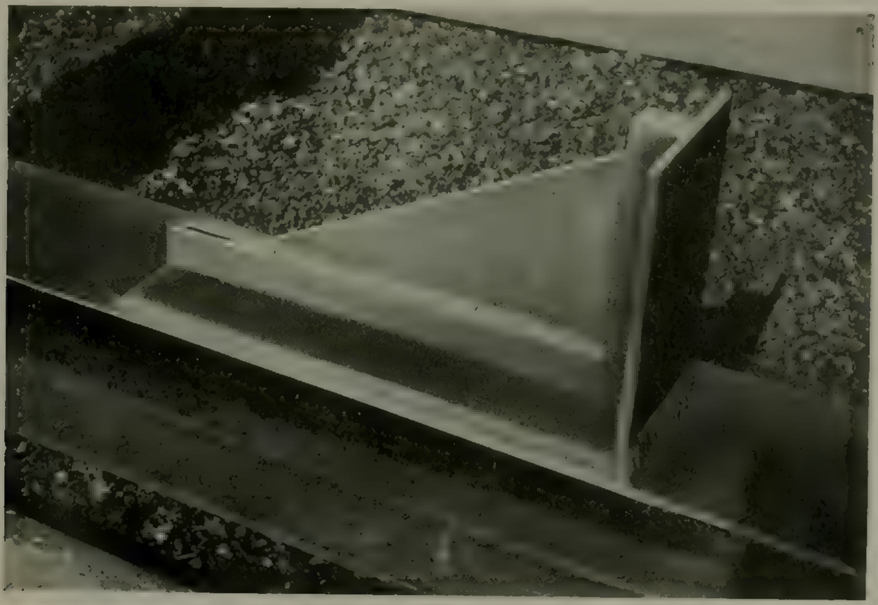


Fig. 82. CRANE RUNWAY BRACKET WELDED TO VERTICAL COLUMN OF FRAMEWORK

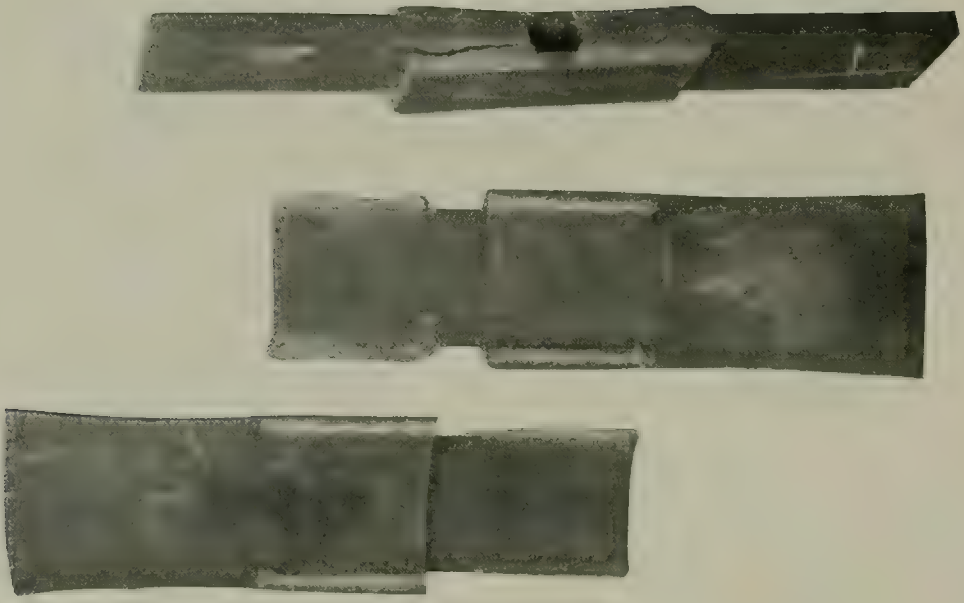


Fig. 83. TENSION TEST SPECIMENS FOR DETERMINING SHEARING STRENGTH OF ARC DEPOSITED METAL PARALLEL TO THE DIRECTION OF STRESS

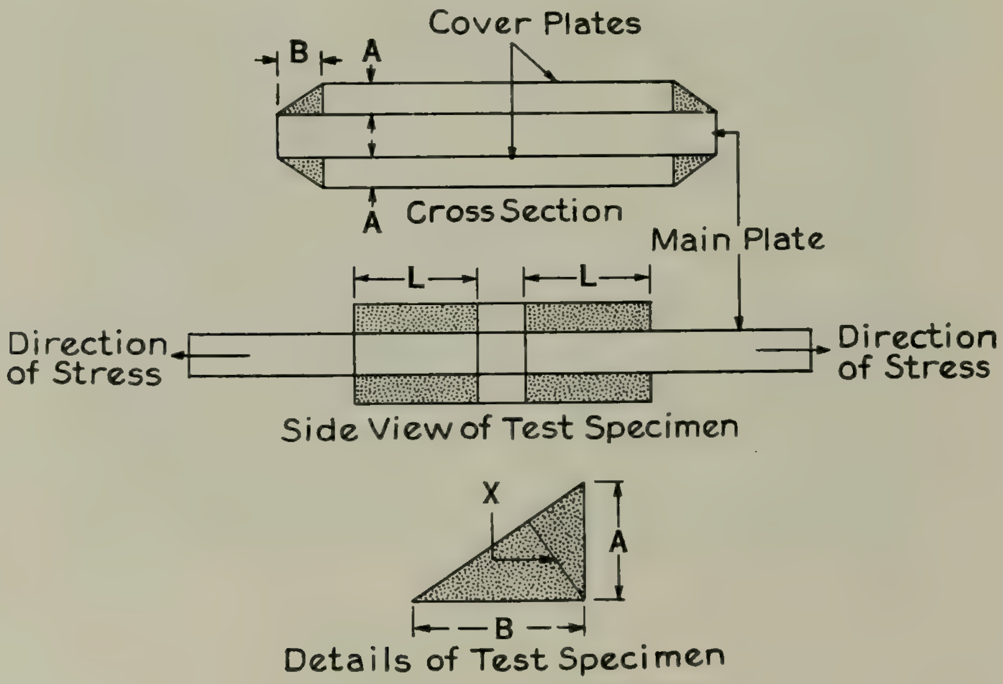


Fig. 84. SECTIONAL VIEWS OF TEST SPECIMENS

## SERIES I

**Table Showing Safe Allowable Shearing Strength of Beads with Axis of Welds Parallel to Direction of Stress in Lb. per Linear Inch at an Allowable Shearing Stress of 9000 Lb. per Sq. In.**

| A Inches | B Inches | X Inches | Safe Shearing Strength of Bead Lb. per Linear Inch |
|---|---|---|---|
| ½ | ½ | 0.355 | 3195 |
| ⅜ | ½ | 0.300 | 2700 |
| ⅜ | ⅜ | 0.266 | 3394 |
| ¼ | ⅜ | 0.203 | 1827 |
| ¼ | ¼ | 0.177 | 1593 |

In the preceding discussion it has been shown that when the stress on the welded structural joint is parallel to the direction of metal deposition in the weld, the weld metal is capable of carrying a certain safe load per running inch. These figures are given in the table just preceding and when these values are used, the load on the weld should be applied as shown in Fig. 84.

Now, if the welds are made in a direction at right angles to the direction of application of load the safe load which the welds will carry per running inch of seam might possibly be somewhat different than those already given. Some tests were made to investigate this question in June, 1925, and the types of specimens were as shown in Figs. 85 and 86. The specimens in Fig. 85 were for tension tests and those in Fig. 86 were for compression tests. The failures are shown in each case. The average ultimate shearing stress obtained was 40,000 lb. per sq. in. for tension and 33,000 lb. per sq. in. for compression.

## SERIES II

**Table Showing Safe Allowable Shearing Strength of Bead with Axis of Welds Perpendicular to the Direction of Stress in Lb. per Linear Inch at an Allowable Shearing Stress for Tension of 10,000 Lb. per Sq. In. and for Compression of 8250 Lb. per Sq. In.**

| DIMENSIONS IN INCHES | | | SAFE SHEARING STRENGTH OF BEAD | |
|---|---|---|---|---|
| A | B | X | Tension | Compression |
| ⅜ | ⅜ | .266 | 2660 | 2195 |
| ½ | ½ | .355 | 3550 | 2930 |
| ⅝ | ⅝ | .437 | 4370 | 3610 |
| ¾ | ¾ | .525 | 5250 | 4340 |

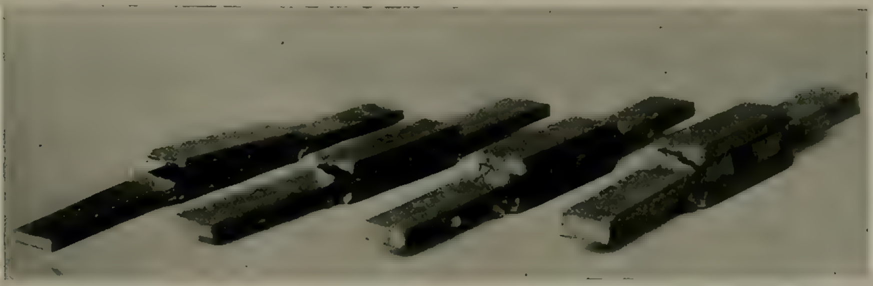


Fig. 85. TENSION TEST SPECIMENS FOR DETERMINING SHEARING STRENGTH OF ARC DEPOSITED METAL AT RIGHT ANGLES TO THE DIRECTION OF STRESS

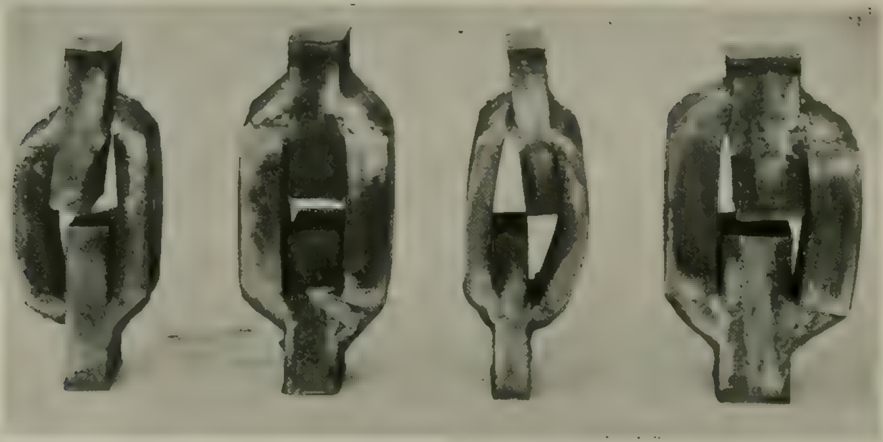


Fig. 86. COMPRESSION TEST SPECIMENS FOR DETERMINING STRENGTH OF ARC DEPOSITED METAL AT RIGHT ANGLES TO THE DIRECTION OF STRESS

## Precautions

It should be noted that these results are based on the assumption that each bead is a flush bead, i.e., that the cross section of the deposited metal is a triangle as indicated in Fig. 84. A slight depression along the center of the bead would seriously weaken the joint and care should be exercised to see that this condition does not occur. A slight reinforcement should be provided by rounding out the sloping side of the bead.

On several existing construction jobs jigs were used to assemble certain parts of the structure in the shop before erection. The use of jigs simplifies the erection work but the welder should be certain that the joints are well clamped and that all dirt and scale are cleaned from the surfaces of the joint which he is about to weld.

Too much emphasis cannot be placed on the need for conscientious first-class work on jobs of this kind. The ordinary bare electrode such as is available for steel welding is used. The manipulation is simple but oftentimes the position which the welder must occupy to weld the joint is such that in order to make the proper weld considerable endurance and conscientious effort are necessary. The welder operator must be dependable and possess a certain amount of job pride.

## Economies Effected

The economies effected by the use of welding instead of riveting may be illustrated by the following example. (See Fig. 87.) The structure in question was a steel framework 40 ft. by 40 ft. by 40 ft. in which 39,334 lbs. of structural steel were used.

| WELDING COSTS | |
|---|---|
| 165 welding hours at (average) 55 cts | $90.75 |
| 150 lb. welding wire at 10 cts | 15.00 |
| | $105.75 |

| RIVETING COSTS (ESTIMATED) | |
|---|---|
| Riveters, 78 hours at $2.25 | $175.50 |
| Rivets, 1800 at 1.235 cts | 22.25 |
| | $197.75 |

The wages for a four-man riveting gang are approximately $2.25 per hour per gang, and it is estimated that about 4500 holes would be necessary for 1800 rivets. On a structure of this type it is estimated that there would be driven no more than 200 rivets per day by one four-man gang. In this comparison there has been no mention made of the following items, some or all of which might enter into the final cost of the construction.

**Welding**

Cost of fuel, in this case electricity, figured as so much per kilowatt-hour; of sand blasting surfaces about to be welded, to free them from rust or scale, a practice sometimes followed.

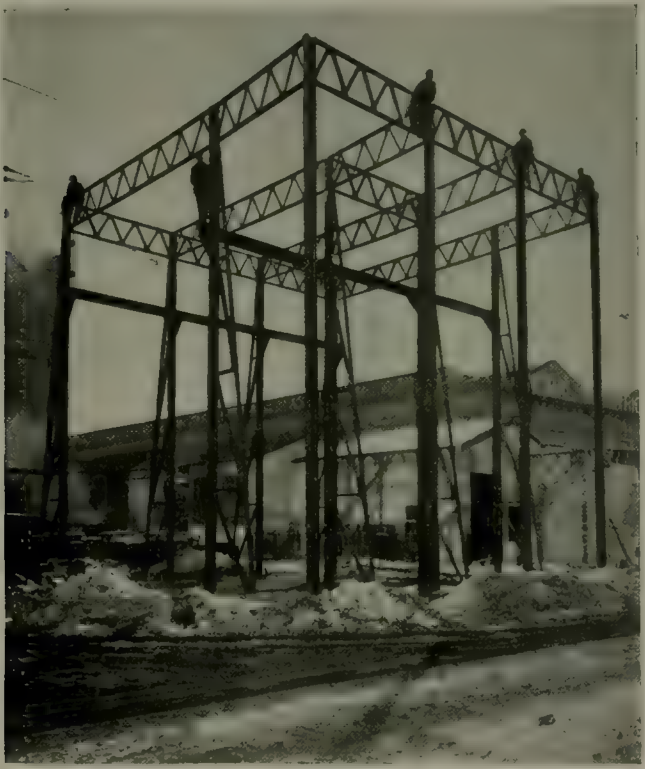


Fig. 87. STRUCTURAL STEEL FRAMEWORK ERECTED BY USE OF ARC WELDING

**Riveting**

Cost of template; of prick punching holes; of punching holes, or of drilling and reaming them. Percentage of rivets lost. Cost of fuel consumed in the rivet heater; of air for air hammer, etc.

Experience shows that at times fabrication can be conducted more easily and at greater convenience by using welding rather than riveting methods. Labor charges are reduced and time is saved because no material need be handled twice and everything can be done in such a way that there is a minimum of lost motion. An additional fact which should be mentioned is that a welder and one helper together are capable of producing more work in a given time than that which could be turned out in the same time by a riveting gang, the latter consisting of from three to five men.

### Recent Example

A recent example of the arc welding process as applied to building construction is shown by Figs. 88 and 89. This building, 40 ft. by 60 ft., of the one-story, mill type, was erected by the Chicago, Burlington, and Quincy Railroad at Eola, Ill. The material used was obtained from the scrap pile and had been used for previous riveted construction, which explains the presence of the rivet holes.

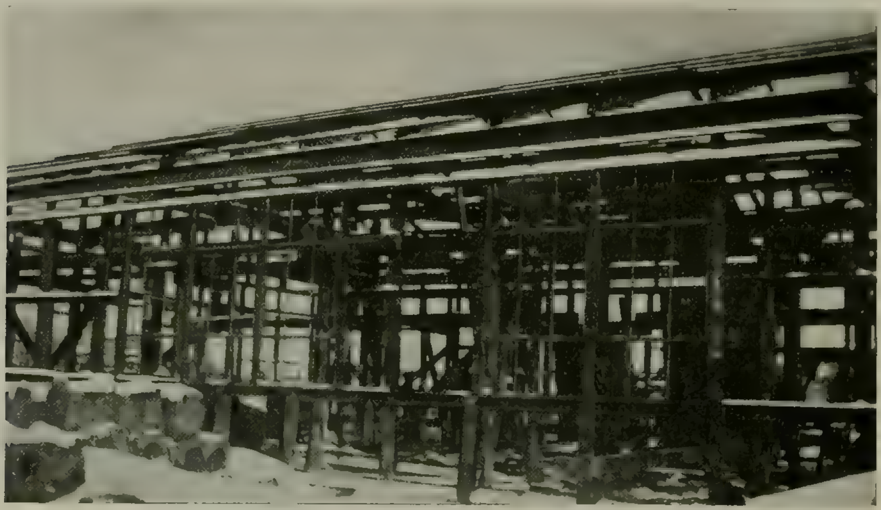


Fig. 88. COMPLETELY ARC WELDED STEEL BUILDING FRAMEWORK

Many of the members are much heavier than necessary but they were in the scrap pile and available for use. They were not used because of their extra weight. It will be noted that there is an absence of gusset plates and connecting angles. As a rule, it is not practicable to eliminate these connecting pieces entirely, but in this case the extra size of some of the members allowed sufficient room for the welds without the use of gussets and clip angles.

A second building of the same dimensions was built by riveting the members and the cost data on both obtained for comparison. The figures are as follows:

**COMPARISON OF ACTUAL COSTS**

| Arc Welding | | Riveting | |
|---|---|---|---|
| PREPARATION | | | |
| Reclaiming, collecting and handling material | $253.61 | Engineering shop details and drawings | $120.00 |
| Material, 25,619 lbs. at ½c | 128.10 | Shop fabrication | 745.00 |
| | | Material, 27,100 lb. at ½c | 135.50 |
| Preparation total | $381.71 | Preparation Total | $1000.50 |
| ERECTION | | | |
| Welder's time and material | $94.86 | Labor and Fitting | $339.00 |
| Cutting, fitting and erecting | 309.63 | | |
| Erection total | $404.49 | Erection Total | $339.00 |
| Grand total | $786.20 | Grand total | $1339.50 |

It will be seen from the above figures that saving in favor of the arc welded building is the saving in structural material, layout, and shop fabrication. The erection costs of the welded building exceed those of the riveted building because all fabrication on the welded building was done during erection, while with the riveted building, this work was done in the shop and is classed under preparation.

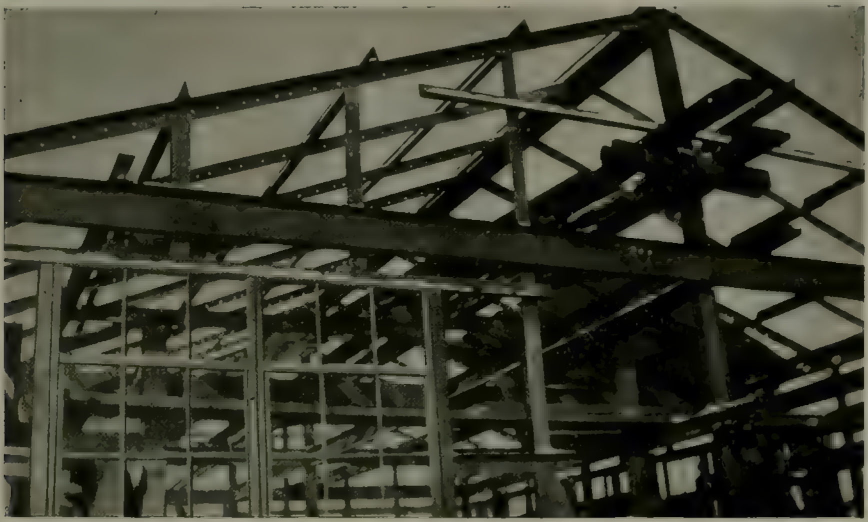


Fig. 89. DETAILS OF ROOF TRUSSES OF BUILDING SHOWN IN FIG. 88

## WELDING STEEL AND IRON ALLOYS

### Malleable Iron

Malleable iron may be welded with either the carbon or **metallic electrode** process, but due to the graphite in the iron structure and the thinness of the surface layer of pure iron a current as low as consistent with good fusion is used. If machining is necessary across the welded section the weld should be annealed. This is due to the fact that the carbon which was set free as graphite by the original annealing process is dissolved in the iron again when the metal becomes molten in the heat of the arc.

### Wrought Iron

The welding of wrought iron is safe and good practice and no bad effects from the heat of the arc should be feared since the carbon content is low (usually less than 0.12 per cent) and is not sufficient to give any hardening effect in the event of sudden cooling. The tensile strength of wrought iron is about 50,000 lbs. per sq. in. and the metal does not harden materially when subjected to sudden cooling. It must be noted, however, that the metal added to the arc process is cast metal and has much less ductility.

### Cast Steel

Cast steel is very readily welded by the metallic arc process with a bare electrode and the arc process is very extensively used in filling up blowholes in large steel castings.

For deep blowholes in large castings, the scale and surface of the metal are chipped off with an air hammer to insure a good, clean metal surface upon which to weld. The deposited metal is then put on in layers and each layer is peened while hot in order to relieve internal stresses in the deposited metal. Each layer is also brushed clean before the next layer is added.

In general the successful welding of cast steel depends upon a careful study of the casting to determine its nature and characteristics. The welding process amounts simply to the addition of a certain amount of cast steel of a given composition, so that a knowledge of the behavior of the metal in the casting as well as of the metal to be added when subjected to the temperature of the arc flame gives the operator a fairly definite idea of the nature of the completed job.

**Steel Forgings**

The problems met in the welding of steel which had been given mechanical treatment are practically the same as those met in the welding of cast steel, so far as the effects of the heat of the arc are concerned. It should be remembered that the base material possesses improved qualities over those of the arc deposited metal since the former has received a certain amount of mechanical treatment while the latter is cast metal.

**High Carbon Steel**

The arc welding of high carbon steel, especially tool steel, is a very uncertain proposition due to a weakening of the metal adjacent to the weld by the "burning out" of the carbon. When welding is resorted to the piece should be preheated and welded while hot.

**Chrome Steel**

Chrome steels are weldable if the carbon content is below about 0.35 per cent. The difficulties encountered are similar to those mentioned in connection with high carbon steel.

**Nickel Steel**

Nickel steel is weldable if the nickel content is not excessive. Pure nickel absorbs an excessive amount of gas when melted by the electric arc. The deposit is porous and possesses practically no strength and for this reason nickel steel electrodes have not been very satisfactory.

## WELDING NON-FERROUS METALS

Non-ferrous metals as commercially used are more or less difficult to weld by the electric arc although some welding is actually done. The application of the electric arc process to the welding of non-ferrous metals is still in its experimental stages. An investigation of this field is now being sponsored by the American Bureau of Welding.

**Copper**

No extensive application has been made thus far in welding copper to copper. The work of this nature which has been done has been accomplished with the carbon arc utilizing the arc merely as a source of heat. The welding of copper to steel is quite common and finds extensive use in rail bonding. (See Fig. 111.) This form of weld is brittle but as there is no mechanical stress, brittleness is not objectionable.

**Brass and Aluminum**

No commercial degree of success has been obtained with these metals as the temperature of the electric arc is too high. Where welding is attempted, the use of the carbon arc with a metallic filler rod is generally advised.

**Bronze**

Bronze if not too high in zinc can be welded by either the carbon or metallic arc. The welding of bronze, using a bronze electrode, is in general successful and has been practiced for several years. One of the most important applications is found in the repair of worn propeller sleeves for ships. (See Fig. 90.) These are subject to quite rapid wear and can be built up and placed in service again by the welding process. Bronze impeller wheels of water turbines which are also subject to considerable wear from the action of water are successfully repaired by the same method.

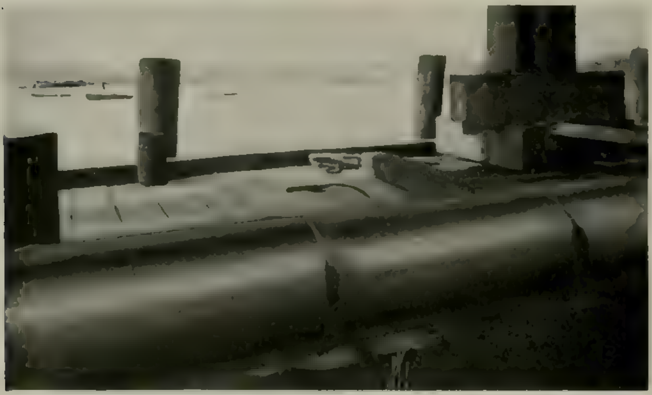


Fig. 90. ARC WELDING A BRONZE PROPELLER SLEEVE

## Monel Metal

Experience has shown that in the arc welding of Monel metal it is difficult to consistently produce welds which are sound and free from blowholes, ductile, and free from shrinkage cracks. With the use of some deoxidizing agent and using reversed polarity, welds have been obtained which were as sound and almost as ductile as welds on ordinary low carbon steel.

The International Nickel Company has made extensive experiments on welding Monel metal with the electric arc as the following extracts from Bulletin No. 108 of that company will show.

Monel metal and nickel can readily be welded by the metallic arc welding process, and the practice of welding either metal by this method is very similar to that followed in welding ordinary low carbon steel. This practice is well known to welders and no general description of it will be given here.

There are, however, in addition to those precautions usually followed in the best steel welding, certain further ones which should be observed in welding both Monel metal and nickel, and these will be described in detail below. When attacking a Monel metal job, if the welder will observe the usual care which he would in a steel job plus these additional features, he will be entirely successful.

The welding of nickel is entirely similar to that of welding Monel metal, and, although what is said below will mention Monel metal only, it applies equally to nickel.

The laying out of work in Monel metal for all types of jobs should be done just as for steel, including such features as bevelling or flanging edges, separating seams for contraction, tacking, use of jigs, etc.

Thin Monel metal sheets up to ⅙ in. should be welded by carbon arc with flanged edges; above this the edges should merely be butted, and over ⅛ in. they should be given a 45-in. bevel in addition. On long seams and on metal over ⅛ in. thick, a separation of ¼ in. to ⅜ in. per foot may be allowed.

One very important feature of any type of fusion welding is to prevent oxidation of the weld. For this reason, welding should be done as much as possible out of drafts, and the weld should not be made in layers, but built up completely in one operation. When this is not done, the black oxide scale on the surface of the first weld layer is melted up in the second layer and produces gas holes. A sound weld cannot be made in layers. For the same reason, it is very important to file, grind or machine off all black oxide scale from edges to be welded.

All Monel metal fusion welds should be built up well above the surface to bring any dross or impurities well above the level of pieces being welded, thus securing a full section of sound welded metal.

In welding sheet or plate the edges should be well backed up by carbon or graphite blocks when possible or with steel if these are not available.

Castings must be preheated to a dull red heat before welding; those of large section particularly should be heated in a furnace or by a fire. Allowances must be made for shrinkage and contraction just as in welding cast steel.

Fusion welds will not be as strong as the original metal, just as in the case of steel welds, but in Monel metal or nickel welds, properly made, a tensile strength of from 40,000 to 50,000 lbs. per sq. in. can be depended on with a moderate ductility, sufficient for example that 90-deg. bends may be made in welded ¼-in. plate.

The principal features of the metallic-arc welding of Monel metal that differ from steel practice are two: (1) A deoxidizer coating should be applied to the bright Monel metal welding rod and (2) the work should be made negative instead of positive as in steel practice.

The latter feature indicates that better results are obtained with d-c. welding of Monel metal than with a-c. arc welding. When the work is made positive the metal of the electrode does not flow freely and continuously but tends to drop off.

The special "deoxidizer coating" which is recommended, consists of the grade No. 2 silicon-manganese-magnesium alloy sold by the Electro Metallurgical Corporation of 30 East 42nd Street, New York City. This contains:

| | |
|---|---|
| Magnesium | 14 to 16 per cent |
| Manganese | 27 to 33 per cent |
| Silicon | 45 to 50 per cent |

It is brittle and can easily be ground and powdered, although it is somewhat inflammable in dust form and care should be observed in handling it.

This alloy is ground to about 50-100 mesh and suspended in a shellac solution (½ lb. shellac to 1 gal. alcohol) to give an oily consistency which will still run. The welding rods of Monel metal are dipped in this suspension and allowed to dry with the powdered coating. This should average about 2 per cent by weight of the welding wire; thus a $\frac{5}{32}$-in. wire will require about a pound of deoxidizer to 600 ft. of wire. After drying the coating adheres and the rods will stand handling and transportation.

The practice for carbon-arc welding of Monel metal is exactly the same as for steel except that a Monel metal filler rod coated with the deoxidizer noted above gives better results than a bright wire. Generally speaking, heavy work can most economically be done by the metallic-arc.

Monel metal or nickel welding rod sizes correspond exactly to steel practice.

| | Current | Work | Welding Rod |
|---|---|---|---|
| Metallic-arc welding | 125-150 | ⅛-¼ | ⅛ |
| | 150-200 | ¼ up | $\frac{5}{32}$ |

**Other Metals and Combinations**

By experimenting further, many operators have learned to weld copper to brass and steel as well as Monel metal, high speed steel, and stellite. These special uses are rather limited in their application and the methods vary, so it is recommended that each operator experiment along the lines suggested by his experience. The difficulty encountered in welding many of the non-ferrous materials, such as copper, nickel, brass, etc., by the electric arc, is the tendency of some of the elements, such as zinc, contained in the part, to be vaporized out of the mass, due to the high temperature conditions. In addition, owing to oxidation and absorption of gases, welds composed of such metals are usually unsound and weak, due to the presence of gas pockets, which are eliminated only by very special precautionary measures. In welding almost any of the non-ferrous metals it is necessary to reverse the polarity on account of the comparatively low melting point of such metals. The work piece will therefore be negative and the electrode positive.

## EXPANSION AND CONTRACTION

### Cast Iron

It is generally known that heat causes a body to expand and that on cooling the body will contract. If a body of metal is heated and then held so it cannot contract, forces, whose magnitude is not generally realized, are set up by the cooling process. If we take a piece of cast iron 1 in. square and 10 in. long and heat it from 50 deg. F. to 500 deg. F., it will increase in length approximately 0.028 in. Now if the ends are held so that the cast iron cannot contract as it cools, the force pulling on the clamps when the iron again reaches 50 deg. will be about 55,000 lb. Since cast iron has no ductility and will not stretch under the application of force, the rod would break, due to the forces set up within it by the contraction of this length of metal in the attempt to make it stretch 0.028 in. in length of 10 in., regardless of how the force is obtained.

### Ductile Materials

If this rod were of wrought iron, however, or of soft steel, the force would be higher, but the metal being ductile would yield and stretch. This action would reduce the force and the rod would not break.

A more exaggerated comparison which brings out the relation of these conditions is as follows: Take a rod of glass and one of lead, 6 in. long and of the same diameter. Clamp one end of the glass rod and apply a force at the other which will bend the rod so that the end deflects ½ in. Before this amount of deflection can be obtained the rod will probably break. Now try to apply the same force to the lead rod in the same manner but do not deflect the end of the rod more than ½ in. It will be found impossible to apply so great a force because the yielding of the lead prevents the building up of the force to this value. A steel rod of the same dimensions may permit of building up the force, but, since it is stronger than the glass, will not break, but will keep the force or strain "locked up" in the metal. By heating it to a fairly high temperature these strains will be relieved by the metal yielding and it will take this permanent deflection when again cooled, just as the lead did at ordinary temperature.

### Locked-up Stresses

These three effects of heat application just discussed are encountered in welding and the success or failure of a weld depends oftentimes upon a careful consideration of them. The rigid nature of cast iron together with its low strength makes the consideration of expansion and contraction of first importance when welding is involved. Wrought iron and low carbon steel will act to a considerable extent as did the lead and by yielding will automatically relieve the stress set up by contraction. Where the contraction is considerable, the "locked-up stresses" in this metal may still be of considerable magnitude. Higher carbon steels will not yield and the stresses will remain locked up unless relieved by some method.

Light hammering of welds in steel plate or tanks will relieve such stresses, but if the stresses are high the shock of a heavy blow may cause the weld to fail. In repairing flaws in large steel castings, it is common practice to "peen" each layer as deposited in order to relieve any locked-up stresses which might be present. In many cases the effects of expansion and contraction can be minimized by arrangement of the parts preparatory to welding, or by the order in which the deposited metal is applied.

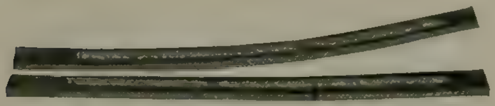


Fig. 91. LONGITUDINAL CONTRACTION OF ARC DEPOSITED METAL

Fig. 92. SHOWING SEPARATION OF DEPOSITED METAL FROM BASE METAL

### Effects of Contraction and How to Resist Them

Where welds are made in more than one layer the locked-up stresses are relieved to some extent by the annealing effect each newly applied layer has on the preceding one. The locked-up stresses will increase with an increase of the carbon content of the steel. Steels of high carbon content (above 0.5 per cent) welded without preheating or annealing are brittle.

The extent of distortion of parts welded by the contraction of the deposited metal will be shown by depositing a layer of metal 10 in. long on a strip of $\frac{3}{16}$-in. steel plate approximately 1 in. wide by 12 in. long, using a $\frac{5}{32}$-in. electrode. The contraction of the deposit will warp or bend the plate. This may be called the longitudinal contraction. (See Fig. 91.)

In the case just mentioned, the base metal upon which the new metal was deposited is a ductile material and can distort itself to compensate for the stresses applied by the cooling action of the arc deposited metal. If, however, the base material is cast iron or other non-ductile material, then the deposited metal is most apt to pull away from the parent metal. This often happens in the case of cast iron welding, if proper care is not taken to avoid the effects of contraction. (See Fig. 92.)

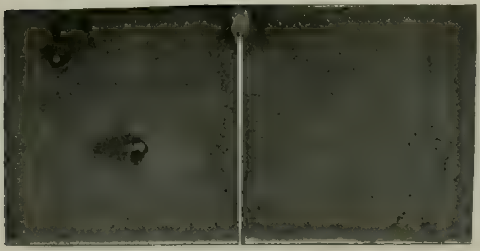


Fig. 93. TRANSVERSE CONTRACTION OF ARC DEPOSITED METAL

Fig. 94. CONTRACTION OF "V" WELD IN THICK MATERIAL

If the edges of two pieces of plate 6 in. by 6 in. by ¼ in. are spaced ⅛ in., and welded together with a short deposit extending approximately ½ in. from the end, when the deposit has cooled it will be found that they will be drawn together, as shown by Fig. 93. This is due to the transverse contraction.

Another example of the contraction effects of the fused-in metal is found in the case of welding together the edges of plates which have been beveled. If two plates approximately 4 in. by 6 in. by ½ in. are welded with beveled edges or buttings, if the plates form a flat surface before they were welded, when the deposit has cooled, the contraction will put them out of line. (See Fig. 94.) Due to the greater opening at the top of the "V," the drawing is greatest on that side of the plate, resulting in the distortion shown.

While expansion and contraction cannot be prevented, their effects can be minimized if certain methods are adopted in arranging the parts preparatory to welding, or by the order in which the deposited metal is applied. For ductile materials where the parts welded are free to come and go by reason of their ductility, elaborate precautions to prevent contraction stresses are probably not advisable. For non-ductile materials and castings or large structures where the contraction effects are liable to be accumulative and to seriously distort the finished product, then considerable attention must be paid to eradicating these harmful effects.

When welding joints formed by plate edges, if the welding is performed by starting at one end of the seam and continuing until the other end is reached, as shown by Fig. 95, as the welding progresses from "A" to "C" the opening at "C" will certainly be drawn together. As the welding continues from "B" to "C," the contraction of the fused-in metal will produce stresses, as indicated by the arrows. When the joint is completed the transverse contraction stresses along the joints will be greatly concentrated at the ends "A" and "C." These stresses impair the quality of the weld and in many cases on cooling, develop a fracture. When a fracture develops where this method is used it usually occurs at the end where the joint is finished.

A method of sequence of welding designed to distribute the heat and contraction stresses more evenly throughout the joint, and thus reduce the amount of drawing and prevent concentration of contraction stresses, is shown by Fig. 96. This order of welding has come to be known as the "step-back" method.

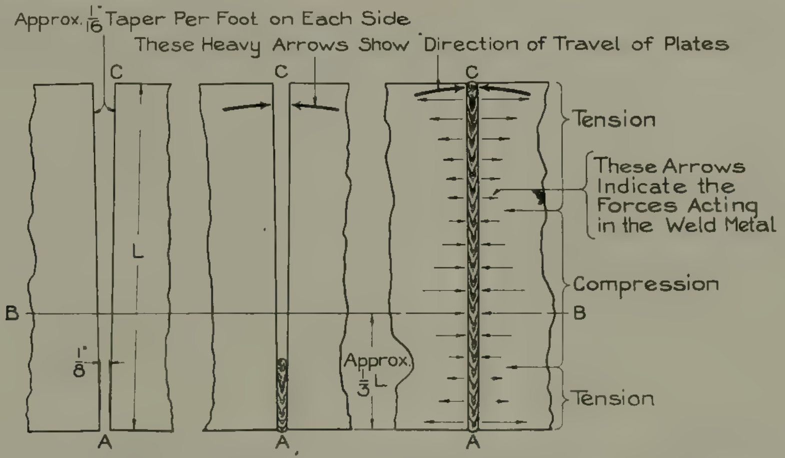

Approx. 1"/16 Taper Per Foot on Each Side
These Heavy Arrows Show Direction of Travel of Plates
C
C
C
L
B
1"/8
A
A
Approx. 1/3 L
A
Tension
These Arrows Indicate the Forces Acting in the Weld Metal
Compression
B
Tension

Fig. 95. LOCKED-IN STRESSES IN A WELD RESULTING FROM CONTRACTION

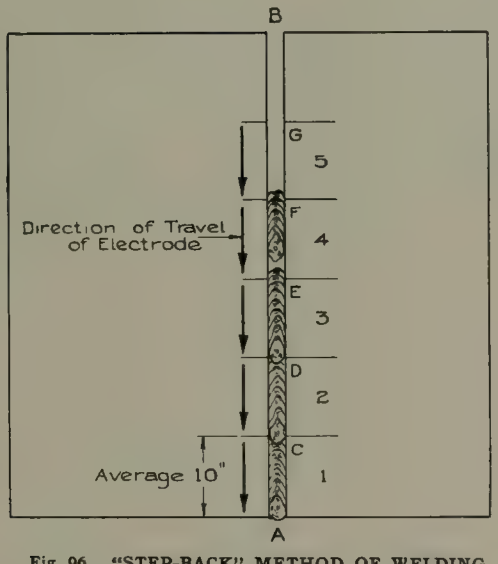


Fig. 96. "STEP-BACK" METHOD OF WELDING TO DISTRIBUTE CONTRACTION STRESSES

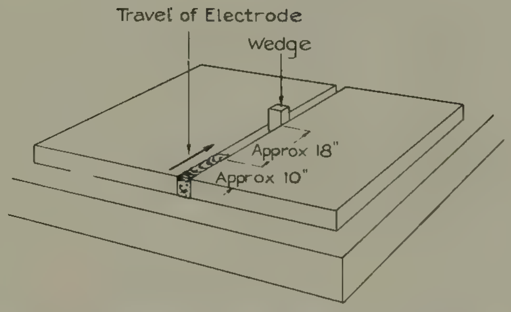


Fig. 97. A METHOD OF REDUCING CONTRACTION BY LOCKING UP THE STRESSES PRODUCED

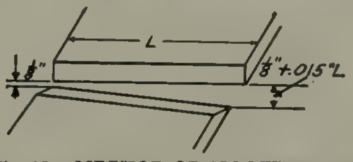


Fig. 98. METHOD OF ALLOWING FOR CONTRACTION WHEN WELDING LONG SEAMS

As shown by the sketch, the deposited metal is applied in sections. The sections 1, 2, 3, etc., are welded in numerical order and in the direction as shown by arrows. By starting at "C" section 1, progressing toward the end "A," section 2 would best be welded in the same manner from "D" to "C."

Each section should be finished at least flush before starting another.

When the parts are rigid and no allowance can be made for contraction, or when it is desired to reduce the drawing of the plates to a minimum, the joint is formed by welding in the order as shown by Fig. 97. When welding long seams by the use of spacing blocks or wedges placed in the opening approximately 18 in. from the section being welded, and toward the end of the seam to which the weld is progressing, the drawing may be reduced to almost nothing.

The exact length of each section may be almost anything within reason but a length of approximately 10 in. is generally found most convenient. The shorter the length of the section, the less the distortion. On extra long seams where allowance can be made for drawing or where distortion is not objectionable, the sections may be longer than 10 in. With short seams or in rigid welding, as in case of fire box cracks, the sections should be relatively short. Where it is necessary to start at one end of a seam and continue to the other end, allowance should be made for contraction by separating the edges more at one end than at the other. Where this is done the joint is made by welding in the order as shown by Fig. 98. For each foot of seam welding (3/8 in. plate thickness) the edges will be drawn together approximately 1/8 in. The exact opening to allow for this method of welding is difficult to give, as there are a number of factors which affect this width of opening, such as the length of the section, speed of welding, plate thickness, etc. (See Fig. 71.) The above figures, however, will serve as a basis to assist in determining the exact opening for the different operations.

When welding heavy sections, such as locomotive frame member and similar parts, it is advisable where possible to spring the butting parts slightly preparatory to welding. Under exceptional conditions an intermittent procedure may be adopted to prolong the operation and reduce the amount of heat developed in the object welded.

As the distortion caused by welding is due to localized or uneven heating, to prevent this distortion preheating may be resorted to, and thus reduce the difference in temperature developed between any two points of the parts affected by the welding.

The practice of preheating for electric arc welding is not resorted to except in some special cases where machinability can be obtained in no other manner and where the internal stresses must be eliminated completely. In some cases, however, it may be advantageous to preheat before welding.

## PREHEATING AND ANNEALING

### Purposes

The effect of sudden cooling of steel or iron which has been melted by the arc is to cause the formation of a hard structure. The degree of hardness for steel of the usual composition will be governed almost entirely by the rate of cooling and by the carbon content. For a given quick rate of cooling, the hardness will increase with an increase of the carbon content, or with a given carbon content the hardness will increase with an increased rate of cooling. The rate of cooling will be governed by the thermal conductivity and heat storage capacity of the part welded. These will vary with the thickness, area and shape of the part welded.

Depending on the kind of metal and the stresses and strains imposed on the part in service, it may be necessary to preheat before welding, to relieve internal strains and to prevent checking of deposit, and also to anneal after welding to remove hardness under the deposit and to more completely relieve the locked-up stresses caused by expansion and contraction.

With the arc process, the deposited metal is usually low in carbon, and its hardness is not greatly affected by the rapid cooling. When welding parts containing about 0.2 per cent carbon or more, if the weld section has considerable thickness, the rapid cooling of the metal adjacent to the weld tends to cause the formation of a hard and brittle zone. This is due primarily to the fact that this zone of metal is heated above its critical temperature by the welding heat, and is subjected to what could be termed a quenching action, due to the rapid absorption of the heat by the colder or unheated interior metal. Where the fused-in metal contains any appreciable amount of carbon and the metal is cooled quickly, it is subject to the same effects.

In addition to the effects on the structure heretofore described, the rapid cooling tends to produce internal expansion and contraction strains. Either of these conditions may be eliminated in most cases if the part welded is afterward annealed. In some instances, as when using medium high carbon electrode material, or when welding non-high carbon steel, it may be necessary to preheat the object welded in order to prolong the cooling and prevent checking of the deposited metal on cooling.

The necessity of adopting this precaution of preheating and annealing fortunately is not required in many cases. It is not usually necessary on plates and shapes of the usual composition up to at least ⅝ in. in thickness, as the rate of cooling of parts of this thickness is not sufficiently rapid to cause serious effects. The character of the metal and the service requirements will govern the welding procedure to be adopted. In general, machinery parts subject to vibratory stresses should be annealed after welding. This annealing should be thorough, giving the entire part a soaking heat and then cooling so that the whole mass can adjust itself to uniform conditions throughout.

The contraction of the deposited metal constitutes one of the most serious troubles of this nature in metallic arc welding. It is responsible for most of the locked-up stresses in welds and the distortion of the parts welded. Proper preheating of the parts before welding and proper annealing treatment after the weld is completed, in most cases removes these stresses.

**Temperature and Appliances**

The preheating temperature of gray cast iron is approximately 500 deg. C., which corresponds to a "faint red" heat. The color becomes more pronounced at from 550 deg. to 600 deg. C. and increases in prominence up to about 700 deg. C. (cherry red) which is the lowest temperature for annealing. The annealing temperature varies from 700 deg. C. (cherry red), for an iron with a carbon content of 0.85 per cent to 900 deg. C. (salmon red) for an iron which contains no carbon Hence we may say that the maximum annealing temperature for the ordinary iron or steel is between 800 deg. and 850 deg. C. (bright red heat).

If no furnace is available (see Fig. 99), a temporary one may be built of fire bricks and the casting heated by coke or charcoal fire. Care should be exercised to see that all parts of the casting are heated uniformly and it is best to heat it up rather slowly. The weld should then be made promptly and the casting allowed to cool down very slowly in the furnace. If the casting has been heated with a charcoal or coke fire it should be covered with ashes and embers while cooling.

Sometimes clean sand is used for the same purpose and even slaked lime may be employed.

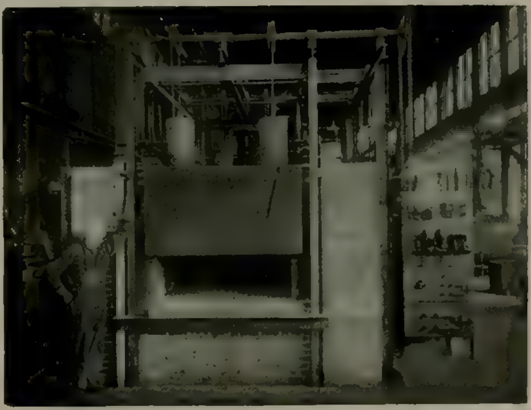


Fig. 99. EXAMPLE OF A PREHEATING AND ANNEALING FURNACE

## ILLUSTRATIONS OF VARIOUS ARC WELDING APPLICATIONS

### Locomotive Shops

Electric arc welding is coming more and more to be recognized as a valuable aid in maintaining service and lessening costs of upkeep on the railroads of this country. A few examples are given here.

Fig. 100 shows a back sheet with Duplex stoker in place. The plate is ⅝ in. thick requiring 22 ft. of welding on the outside sheet, including welding around the two duplex stoker posts. This consumed 25 lb. of $\frac{5}{32}$-in. electrode using 150 amperes. The inserted sheet, after positioning, was tacked at two-foot intervals to hold in place. Then the top seam was welded completely across, using the step method.

Fig. 101 gives an inside view of back sheet similar to the one shown in Fig. 100. The plate in this illustration is ⅜ in. thick, requiring 22 ft. of welded seam and using 20 lb. of $\frac{5}{32}$-in. electrode at 150 amperes.

Fig. 102 is a close-up view of a locomotive shell showing flexible staybolt sleeves arc welded. The procedure is similar to that of welding flues, namely, welding the circle in two halves beginning at the bottom, proceeding half way around, stopping at the top, then beginning again at the bottom, proceeding up the other side and meeting the previously deposited bead at the top.

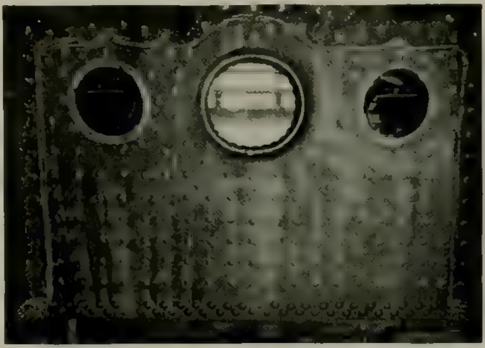


Fig. 101. INSIDE VIEW OF LOCOMOTIVE BACK SHEET COMPLETELY WELDED WITH DUPLEX STOKER IN PLACE

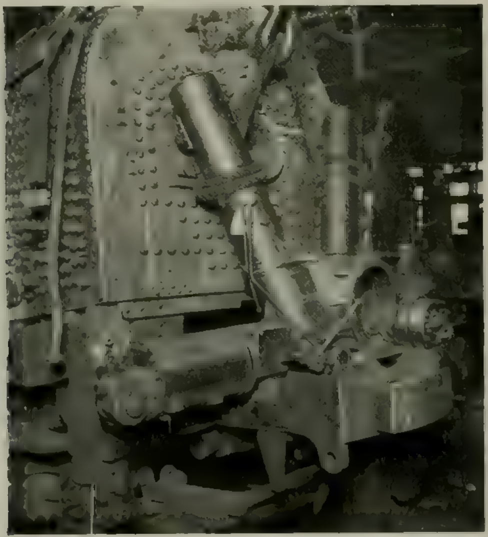


Fig. 100. LOCOMOTIVE BACK SHEET WITH DUPLEX STOKER, ARC WELDED AS INDICATED BY CHALK MARK

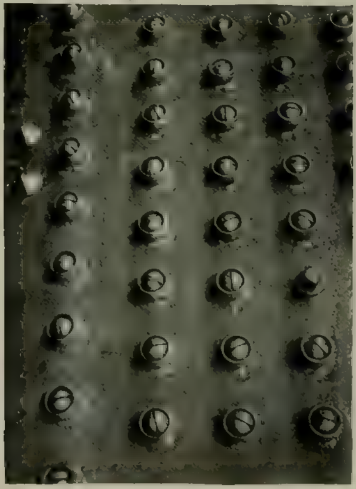


Fig. 102. CLOSE-UP VIEW OF LOCOMOTIVE SHELL SHOWING METHOD OF ARC WELDING FLEXIBLE STAY-BOLT SLEEVES

Fig. 103 is a general view of a locomotive shell showing flexible staybolts. The illustration shows the process of manufacture. The shell contains a total of 1417 flexible staybolts.

Approximately 125 of these sleeves can be welded by a competent operator in an eight-hour day using $\frac{5}{32}$-in. electrode and 150 amperes.

Fig. 104 shows the various stages in the repair of a broken locomotive cylinder. This cylinder was repaired and put back in service in four days using the studding method of electric arc welding. The upper left illustration on page 102 shows the cylinder as it came into the shop. At the upper right the cylinder is chipped, studded and has the valve chamber ring in place. This ring, which is made up of steel forging, has been machined and fitted to the valve chamber. The forging and machine work on the ring is often done even before the crippled locomotive is received in the shop. From the round-house or wherever the engine has been inspected and welding recommended as the remedy, the engine number and the nature and location of the break are sent to the locomotive repair shop. Immediate steps are taken to have the necessary parts prepared so that upon receipt of the engine, chipping and studding may immediately be done and the ring set in place ready for welding. The same method of procedure is followed with the segment of the cylinder ring itself, which is shown missing. These parts are generally carried in stock ready for immediate use on demand and no time is lost in fitting them to the cylinder.

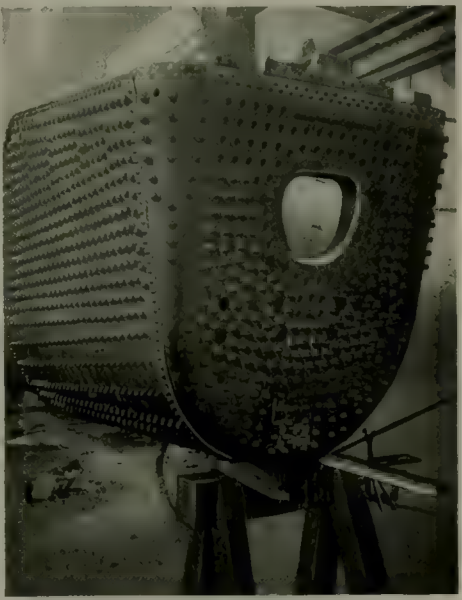


Fig. 103. LOCOMOTIVE SHELL SHOWING FLEXIBLE STAYBOLT THE SLEEVES OF WHICH ARE ELECTRICALLY ARC WELDED

The illustration at the lower left shows the cylinder partly welded. Note the valve chamber ring A, and the sheet steel steam pipe B. At the lower right is shown the completed cylinder with valve heads in place ready for service. This particular job required a total of 144 hours, in which time 300 lb. of $\frac{5}{32}$-in. electrode were deposited with 150 amperes current. The casting required a total of 128 studs.

| | |
|---|---|
| Cost of studs and labor to install | $25.00 |
| Cost of dismantling | 28.00 |
| Cost of both rings | 35.00 |
| Cost of machining rings in place | 8.00 |
| Cost of electric power | 22.00 |
| Cost of electrode material | 30.00 |
| Cost of welding labor | 108.00 |
| Total cost of reclaiming cylinder | $256.00 |

It might be interesting to note that the cost of a new cylinder for a locomotive of this type would be $1100 without considering the time lost while waiting for the cylinder and installing same. It may also be interesting to know that a certain railroad has reclaimed 167 cylinders similar to the above during the past two and one-half years, and previous to this time records show that 250 cylinders were welded successfully, making a total of 417 reclaimed cylinders placed in service with not one failure to report.

Steel studs are used where the weld must be made on cast iron in the repair of locomotive cylinders. The studs are inserted to take the contraction stresses caused by the cooling of the deposited metal and prevent fracture at the junction of the cast iron base metal and the weld metal.

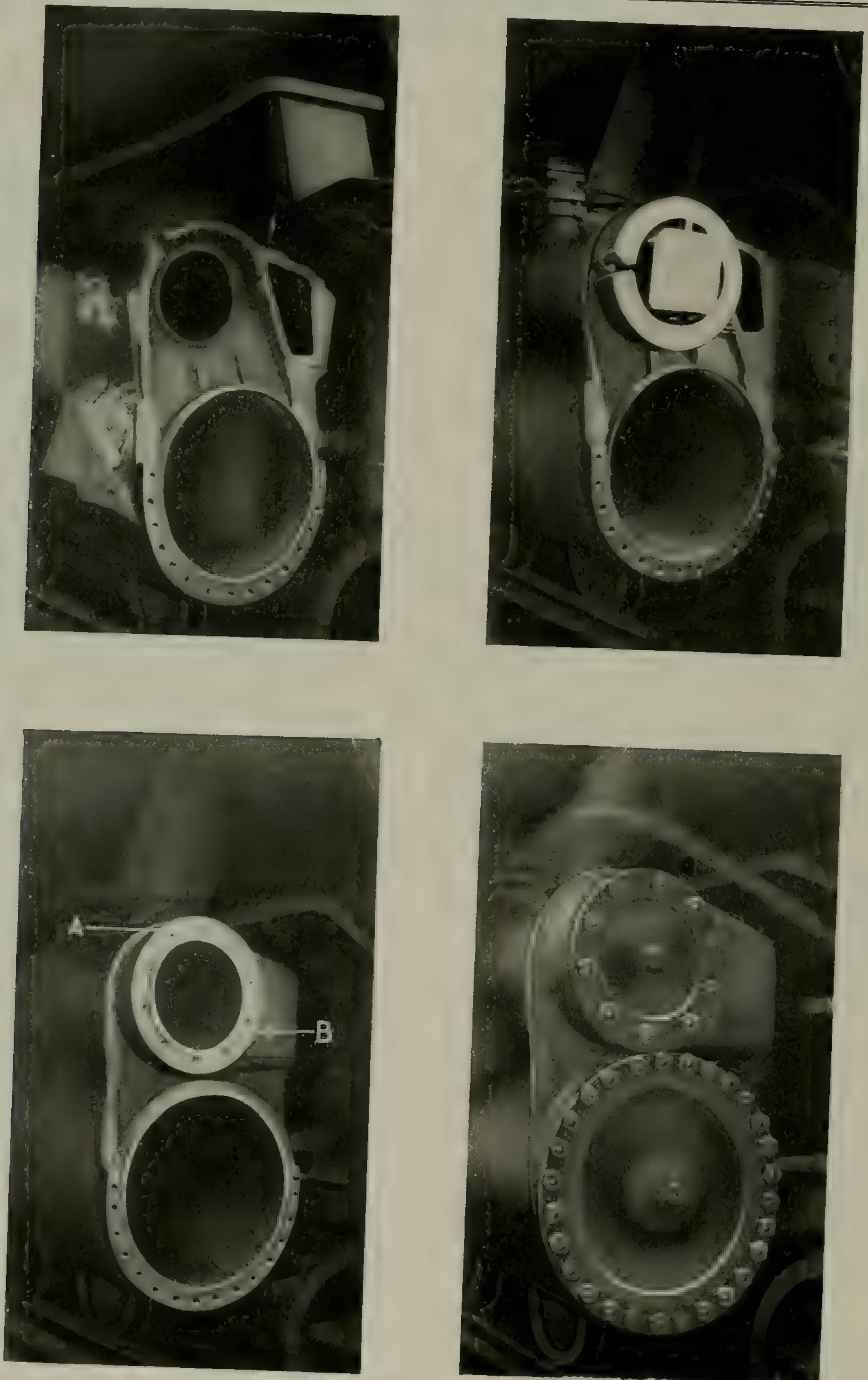


Fig. 104. BROKEN LOCOMOTIVE CYLINDER SHOWING VARIOUS STAGES IN THE REPAIR BY MEANS OF ELECTRIC ARC WELDING

Fig. 105 illustrates the studding process. The surface of the break is chipped off and holes are drilled and tapped about 1 to 1½ in. deep, in the cast iron. The illustration shows the studs inserted. These studs are standard ¾-in. bolts screwed in tight. Before the welding is started these bolts will be cut off about ½ in. above the surface of the cast iron.

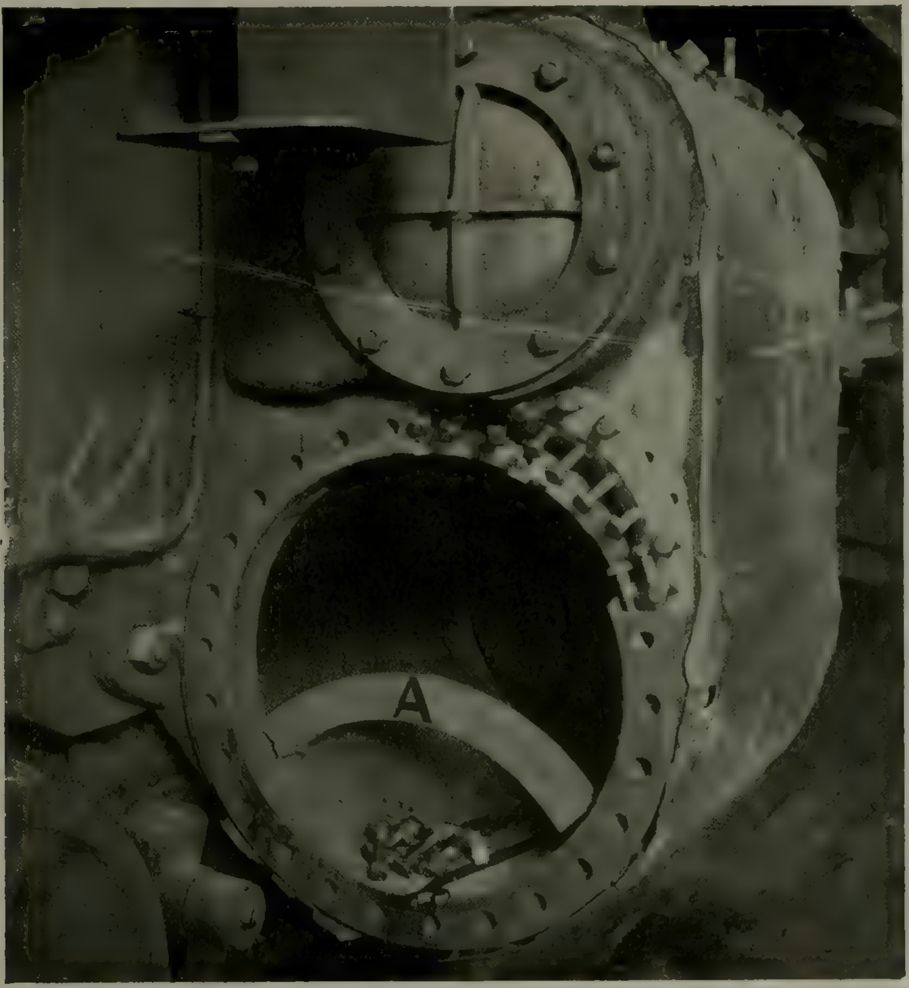


Fig. 105. PREPARATION OF BROKEN LOCOMOTIVE CYLINDER FOR REPAIR BY ELECTRIC ARC WELDING

After the metal has been built up sufficiently, a seating place for the new section of the end ring "A" is chipped or ground and the piece put in place. When the piece has been seated, it is welded solidly into place. Holes are then drilled and tapped in the new piece, the cylinder head applied and bolted into place. In this way the engine is put back into active service in a few days, while weeks of delay would be the result if it were necessary to install a new cylinder.

Fig. 106 shows a locomotive side frame repaired in place by insertion of a forged steel section. This repair was made by cutting out the faulty section by means of the gas cutting torch and a new section forged so as to fit. In making the upper weld, the frame itself was chipped to a chisel edge, the point of which reached almost to the flat top of the forged piece, leaving a gap of ¼ in. One bead is then used to close opening and unite the upper part of the forging to the frame. The weld is then continued layer on layer in crescent form and working out. This work can be done by one operator working on one side at a time or by two operators, one on either side of the frame, working simultaneously. The lower weld is made by "V"-ing to a chisel point both the frame and forged piece, with a space of ¼ in. between the chisel edges. This space is then filled up with a bead run vertically, beginning at the bottom and finishing at the top, thus joining the two pieces. Proceeding as before, weld over the first bead and continue outward until the "V" is completely filled up.

Strict instructions were given to the operator that all of the welding must be done with the electrode pointing perpendicular to the work. Two men welded this frame in 10 hours each, totalling 20 hours of welding labor, using 35 lb. of electrode $\frac{5}{32}$ in. in diameter with 165 amperes.

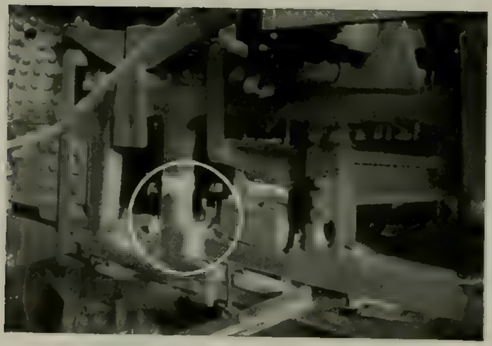


Fig. 106. LOCOMOTIVE SIDE FRAME REPAIRED IN PLACE BY THE INSERTION OF A FORGED STEEL SECTION ELECTRICALLY ARC WELDED

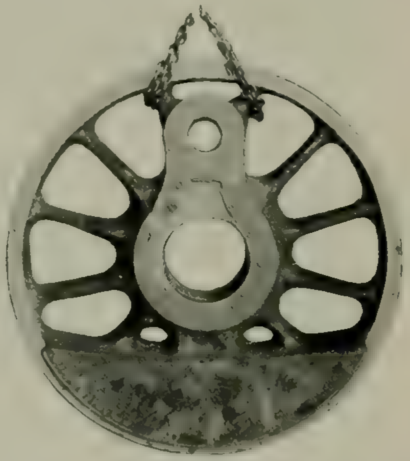


Fig. 107. LOCOMOTIVE DRIVING WHEEL CENTER SALVAGED BY ARC WELDING TO BUILD UP UNDERSIZED HUB

Two hours' time was required to forge the added piece in the blacksmith shop and eight hours additional for the machinist to prepare the piece. The machining consisted of shaping and chipping the block. This procedure, therefore, required a total of 10 hours preparatory labor. The only dismantling of the locomotive that was necessary was the dropping of a pair of wheels near the fracture.

Fig. 107 illustrates a use of arc welding in reclaiming undersized parts. This undersized new wheel in a locomotive plant was salvaged by depositing 90 sq. in. of metal ¼ in. high at the hub and crank pin hole. The building up required two hours' time using $\frac{5}{32}$-in. electrode at 150 amperes.

Fig. 108 shows an assortment of sand domes at a locomotive plant, each of which necessitated 40 ft. of seam welding. One seam on each dome can readily be distinguished at the bottom of the domes. The second seam near the top of the dome has been ground off and when complete finishing touches have been made and the dome is painted, the seams cannot be detected. The 4 ft. of seam per dome was welded by one operator in eight hours, using 15 lbs. of ⅛-in. electrode at 125 amperes. The sand domes are made of ¼-in. plate.

Fig. 109 shows an example of the compactness obtained by the use of arc welding. This locomotive tender tool box required 22 ft. of seam welding and is one of a pair, each requiring four hours of welding labor, consuming 8 lb. of $\frac{5}{32}$-in. electrode at 150 amperes. The plates are $\frac{5}{16}$ in. thick.

The illustrations shown cover some of the applications of electric arc welding in locomotive shops. Many others could be given but space does not permit. Fig. 47 shows an example of arc welded flues in a locomotive fire box. Other applications which might be mentioned are the building up of moving parts to compensate for wear, repairing flat spots in locomotive tires, building up worn flanges, patching fire boxes, etc. Automatic arc welding is suitable for certain salvage operations in locomotive shops. In this category are the rebuilding of worn locomotive guide rods and driving wheel centers.

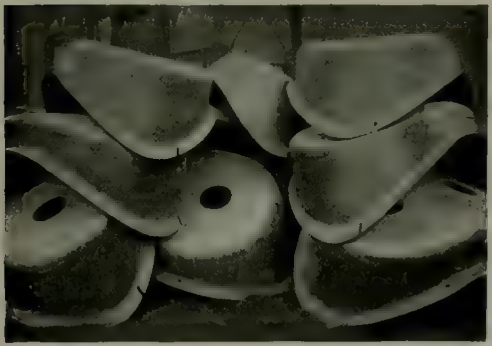


Fig. 108. AN ASSORTMENT OF LOCOMOTIVE SAND DOMES EACH OF WHICH NECESSITATED 40 FT. OF ELECTRIC ARC WELDING

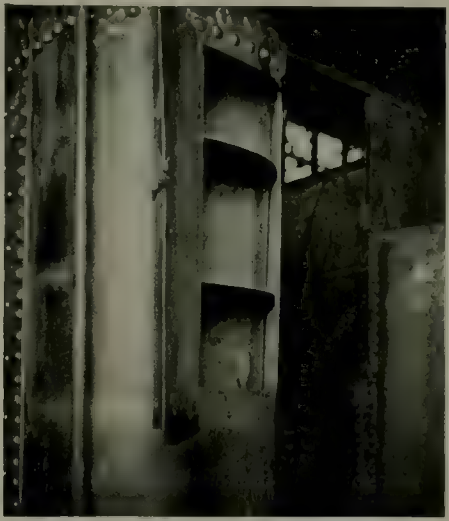


Fig. 109. LOCOMOTIVE TENDER TOOL BOX WITH DOOR OPEN, COMPLETELY ELECTRIC ARC WELDED INCLUDING SHELVES AND HINGES

**Electric Railways**

In the electric railway field, arc welding is used for maintenance work and making repairs. Car wheel flanges are built up with the metallic arc thus adding from twenty to thirty thousand miles of wear to the wheel. (See Figs. 119 and 120.) Axles are being built up in some instances, but as yet this practice has not been universally adopted.

Fig. 110 illustrates a method of attaching steel rails to a steel cross tie. The foot of the rail is welded to the tie with a 6-in. bead on each side making a total of 24 in. of weld for each tie. This weld consumes approximately 60 minutes of time and is completed by one man.

Fig. 111 shows a rail bond attached to a steel rail by means of an electric arc weld.

Fig. 112 gives an idea of the extent to which the arc welding process will save time and money in the car shop. The worn armature shaft in the foreground has been built up by the hand method and the armature was not dismantled. If the arc welding process is not used the shaft must be scrapped. In Fig. 113 are shown several worn armature shafts which have been built up by the arc welding process and are now awaiting machining before being put back into service.

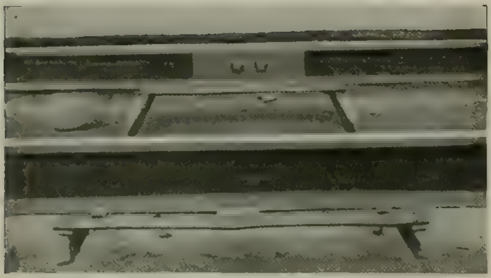


Fig. 110. ARC WELDED STEEL CROSS TIE AND FISH PLATE

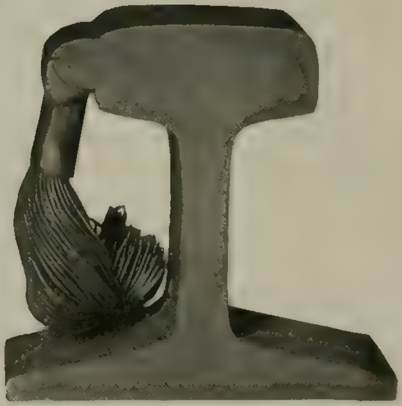


Fig. 111. CROSS SECTION OF RAIL SHOWING ATTACHMENT OF RAIL BOND

Fig. 114 is a close-up view of the end of a motor shaft which has been built up by an automatic arc welder. This surface when machined down to size gives a smooth homogeneous bearing surface. With this process $\frac{1}{8}$-in. or $\frac{5}{32}$-in. wire with 150 to 170 amperes is used and a speed of travel of about 5 in. per minute at the arc is maintained.

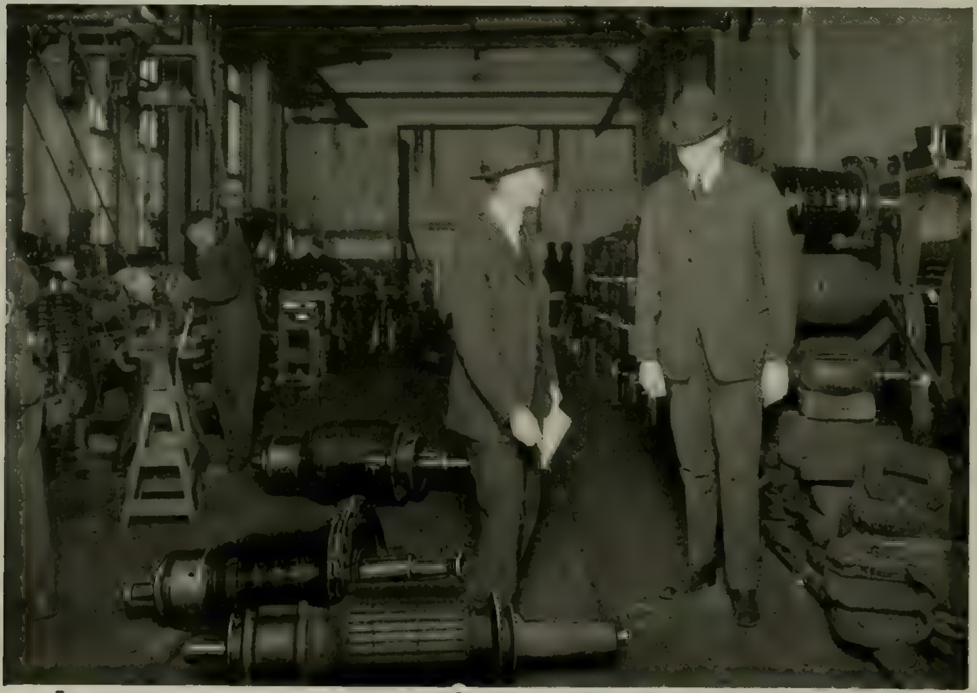


Fig. 112. STREET RAILWAY CAR SHOP SHOWING REBUILT ARMATURE SHAFTS

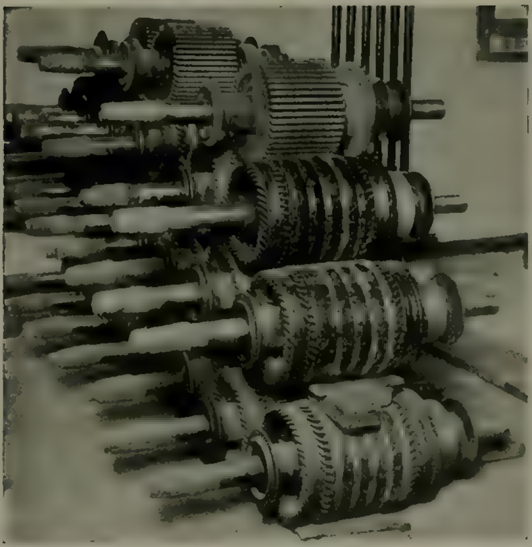


Fig. 113. A GROUP OF WORN ARMATURE SHAFTS REBUILT AND READY FOR MACHINING

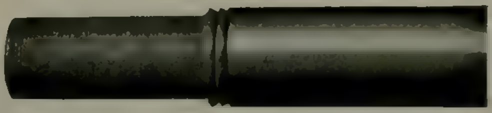


Fig. 114. MOTOR SHAFT WITH WORN BEARING SURFACE REBUILT BY AUTOMATIC ARC WELDING

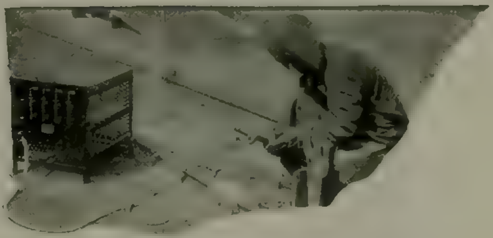


Fig. 115. RESISTOR ARC WELDER AT WORK

Fig. 115 shows a resistor arc welder in operation building up a flat spot in a rail. This type of apparatus is often used where portability is the deciding factor and power cost is of no consideration. A motor-generator arc welding set is more efficient in the use of power.

Arc welding is of considerable assistance in the repair of broken parts of motors. Figs. 116 and 117 show two repairs made on motor casings. The casing shown in Fig. 116 was broken in twelve pieces.

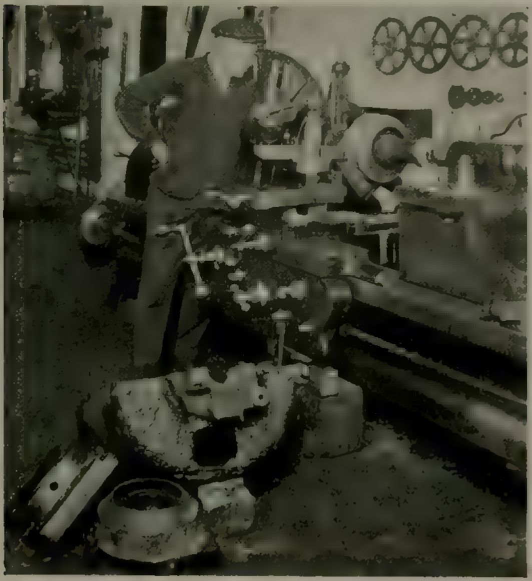


Fig. 116. MOTOR CASING REPAIRED BY ARC WELDING

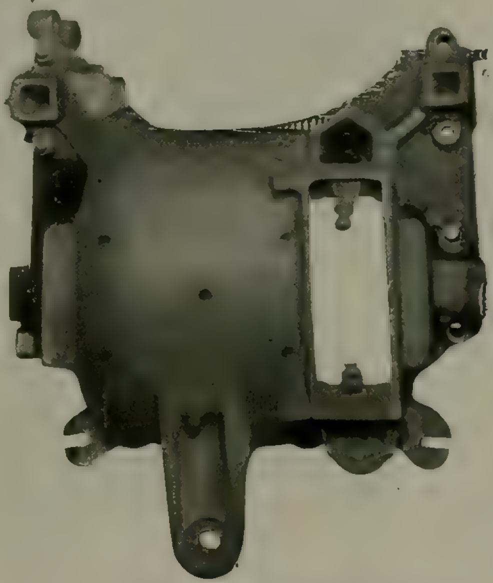


Fig. 117. MOTOR CASING RECLAIMED BY ARC WELDING FORMERLY SCRAPPED

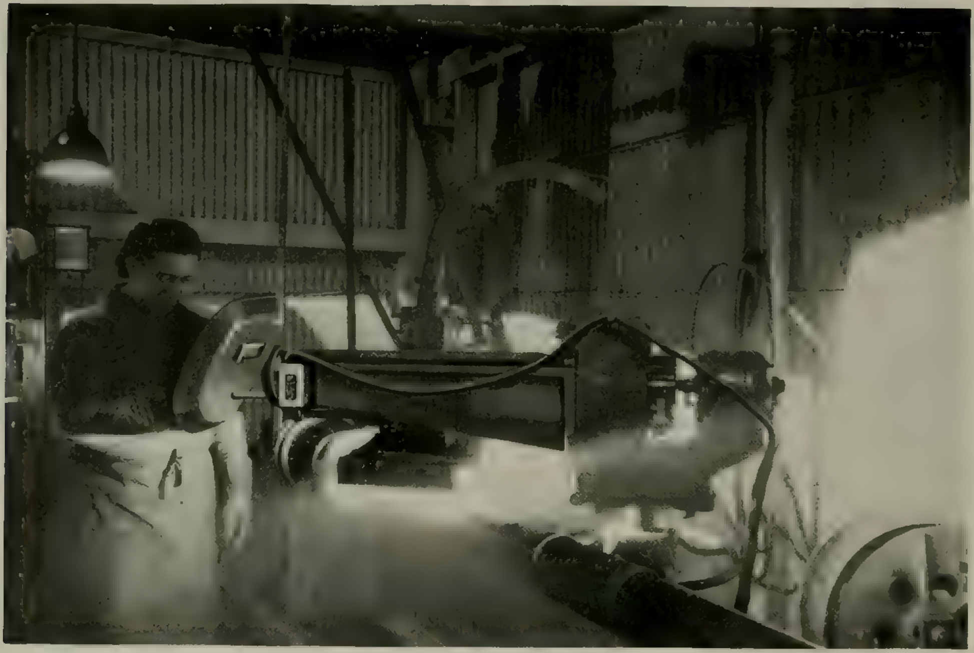


Fig. 118. REBUILDING WORN CAR AXLES WITH AN AUTOMATIC ARC WELDER

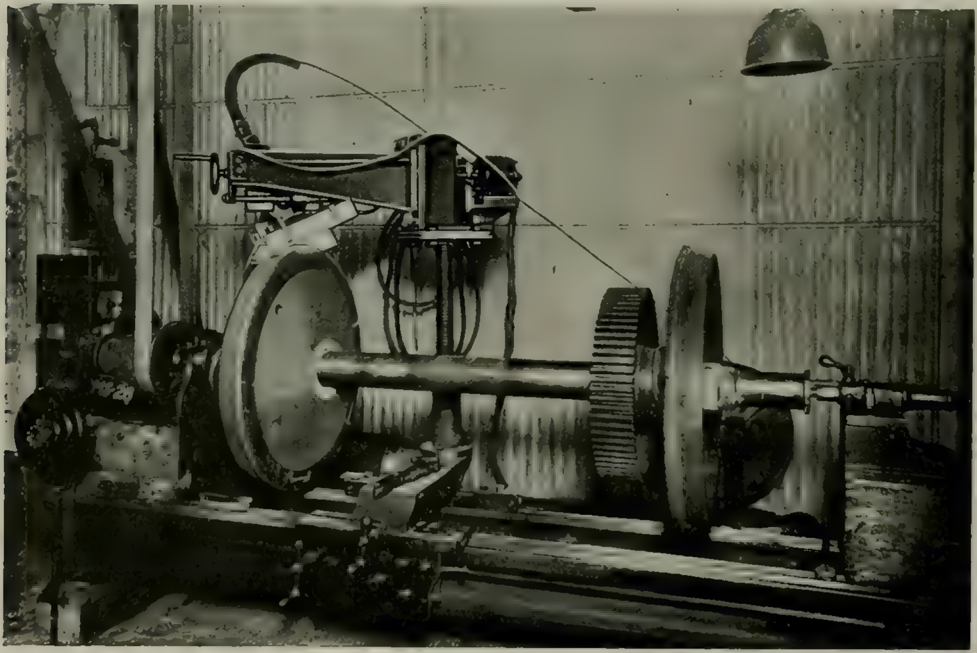


Fig 119. REBUILDING WORN CAR WHEEL FLANGES WITH AN AUTOMATIC ARC WELDER

Electric welding is proving of great assistance in the maintenance of equipment on street railways. The replacement of bearing surfaces on car axles and the rebuilding of new flanges on new wheels are examples. Fig. 118 shows an automatic welder building up a worn car axle. A $\frac{5}{32}$-in. electrode and 200 amperes are being used here. Fig. 119 shows the worn flanges on a pair of wheels being rebuilt with an automatic arc welder. Fig. 120 shows wheels and axles after welding. The axle nearer the camera has been machined in a lathe and is ready for mounting the wheels.

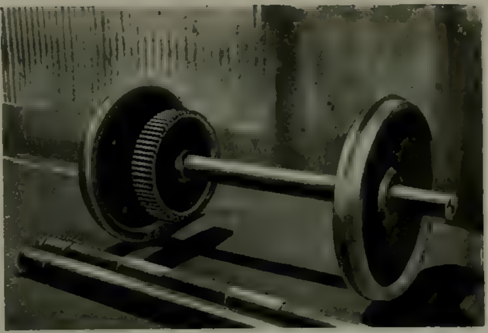


Fig. 120. WORN CAR WHEEL FLANGES AND AXLES REBUILT BY ARC WELDING FOR FURTHER SERVICE

**Tank Manufacturing**

Several examples of arc welding applications in tank manufacturing processes are shown by the following illustrations.

Arc welding plays a considerable part in the making of steel tanks as shown by Figs. 121, 122 and 123. Fig. 121 illustrates a type of oil switch tank. Fig. 122 shows a different type of steel tank for holding hot oil. The rim is made of ½-in. boiler plate, the tank of $\frac{3}{16}$-in. plate. The size of the tank is 15 in. by 30 in. by 21 in. Fig. 123 shows the difference in the rate of production by hand and by automatic arc welding.

The tank shown at the right in Fig. 121 is approximately 9 ft. long and is built of steel ¼ in. thick. The seam was beveled with a total opening of 90 deg. and welded with $\frac{5}{32}$-in. electrode using 170 amperes.

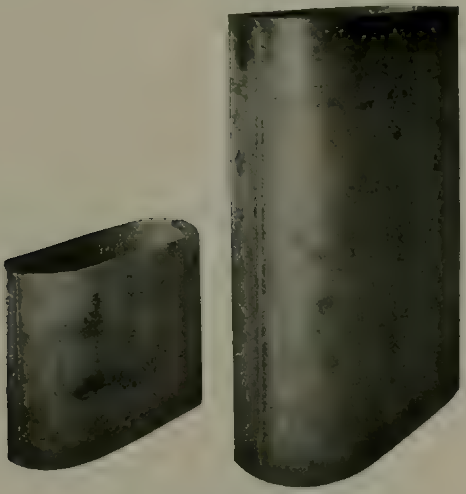


Fig. 121. ARC WELDED STEEL TANKS FOR OIL SWITCHES

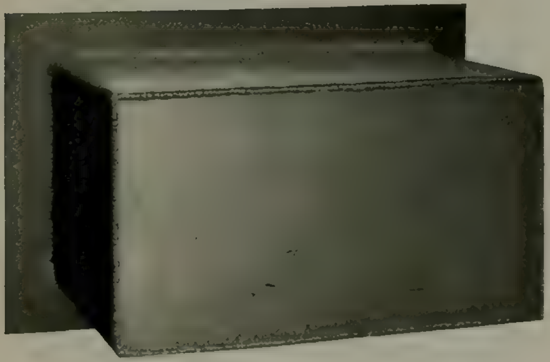


Fig. 122. ARC WELDED STEEL TANK FOR HOLDING HOT OIL

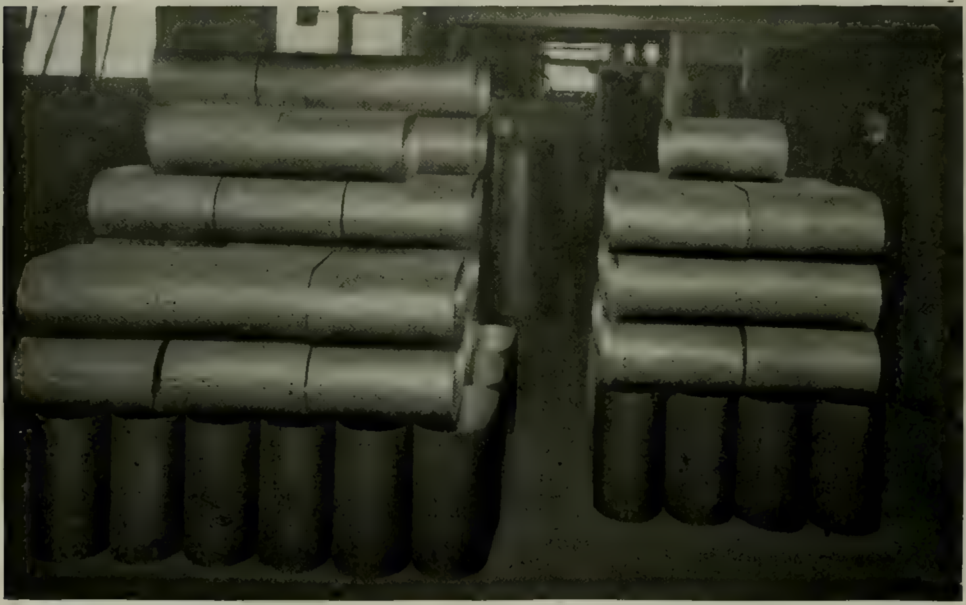


Fig. 123. COMPARISON OF A DAY'S WORK BY THE AUTOMATIC PROCESS (left), AND A DAY'S WORK BY THE HAND PROCESS (right)

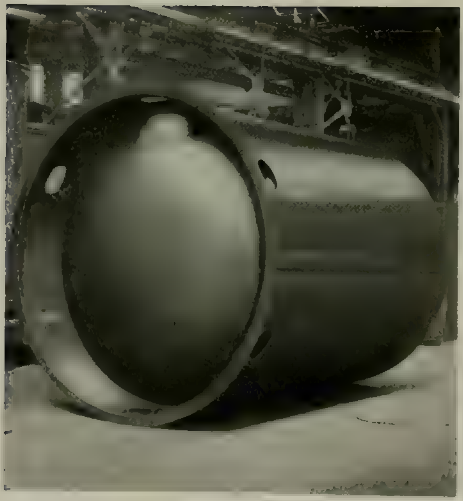


Fig. 124. ARC WELDED 220,000-VOLT OIL CIRCUIT BREAKER TANK

Figs. 124 and 125 are two different views of a 220,000-volt oil circuit breaker tank with all seams arc welded. The size of the tank may be judged by the size of the operator who is standing at the side of the tank.

Fig. 126 illustrates the type of welding used on a large steel tank where reinforcing is desirable in order to insure that the joint will stand up under the service pressure.

Tubes for circulating a cooling medium in tanks are easily and firmly put on by the arc welding process as shown in Fig. 127.

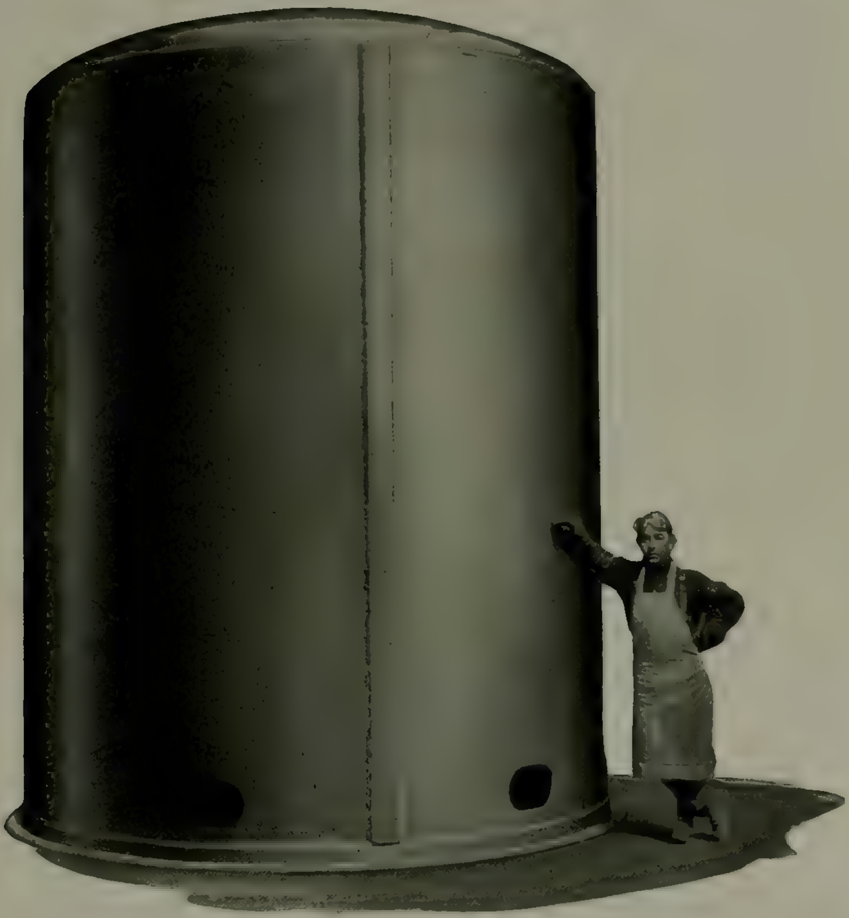


Fig. 125. 220,000-VOLT OIL CIRCUIT BREAKER TANK SHOWN IN FIG. 124

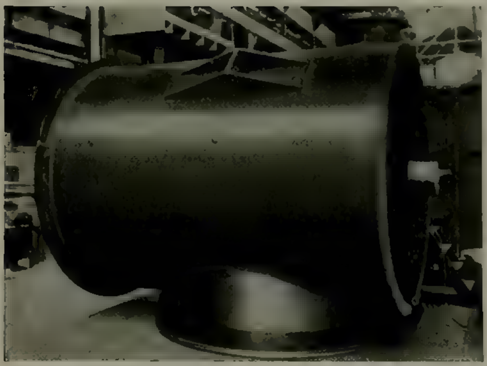


Fig. 126. CONDENSER BOILER SHELL WITH ALL SEAMS ELECTRICALLY ARC WELDED

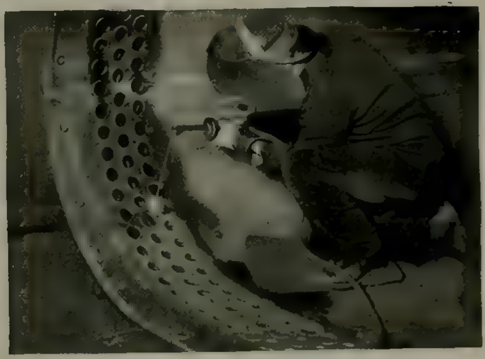


Fig. 127. WELDING TUBES IN TANKS

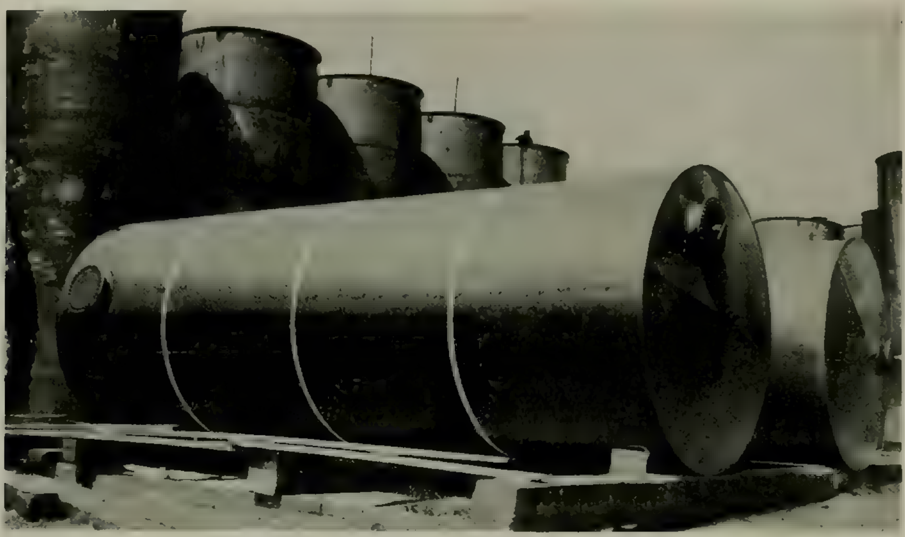


Fig. 128. OIL STORAGE TANKS WITH SEAMS ELECTRICALLY WELDED

Fig. 128 illustrates a type of tank which the use of the electric welding arc makes possible. The necessity for caulking is eliminated, and a smooth, leakproof tank may be produced in a shorter time by this process than by any other method.

Fig. 129 illustrates the application of the electric welding arc to the manufacture of galvanized iron tanks. The illustration shows one month's production of one factory. These tanks carry a working pressure of about 3 lb. per square inch. There are three longitudinal seams which are welded at the rate of about 80 feet per hour with a special electrode.

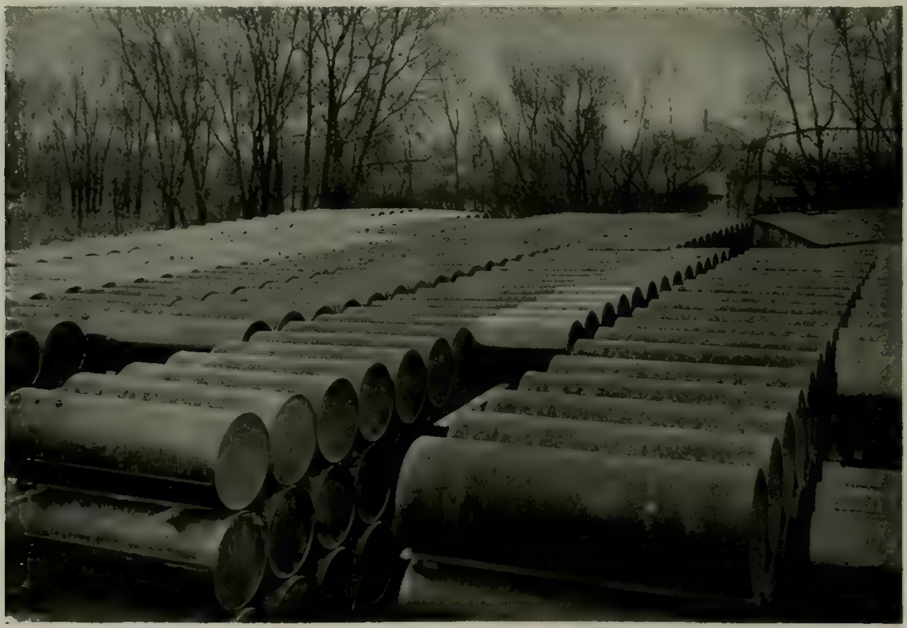


Fig. 129. GALVANIZED IRON GASOLINE TANKS WITH SEAMS ELECTRICALLY WELDED

**Steel Construction**

At present the use of arc welding is increasing in the field of steel construction, but there still remains a great amount of experimenting and investigation which must be done. A few applications are given below.

An arc welded oil storage tank has considerable advantage over a riveted tank because of its tightness and strength. The saving in eliminating leakage amounts in most cases to several thousand dollars per year per tank. Fig. 130 shows a tank 43 ft. in diameter and 20 ft. high under construction. All joints are arc welded. When completed the tank was filled with kerosene and, after 36 hours, was found to be without leaks.

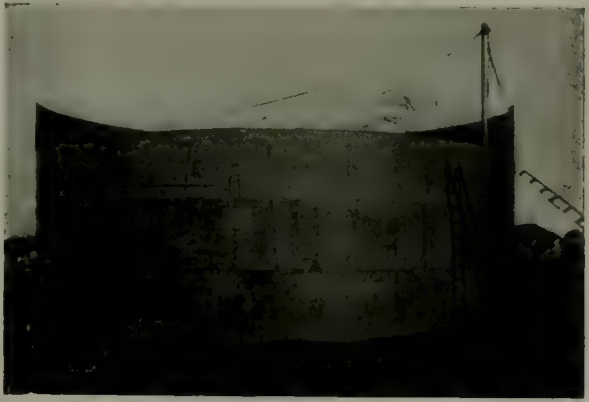


Fig. 130. OIL STORAGE TANK UNDER CONSTRUCTION

In Fig. 131 is shown an all arc welded gas holder of 15,000 cubic feet capacity. The bottom is of $\frac{3}{16}$-in. plate with $\frac{3}{4}$-in. laps. The sides are $\frac{1}{4}$-in. plate for the first course, and $\frac{3}{16}$-in. plate for the second and third courses. All side seams are $\frac{3}{4}$-in. lap with a full weld on the inside and tack welds on the outside. The container and crown are No. 10 gauge material, with laps welded on both sides for the container and on the outside for the crown. The construction required about six weeks with two welders and three mechanics.

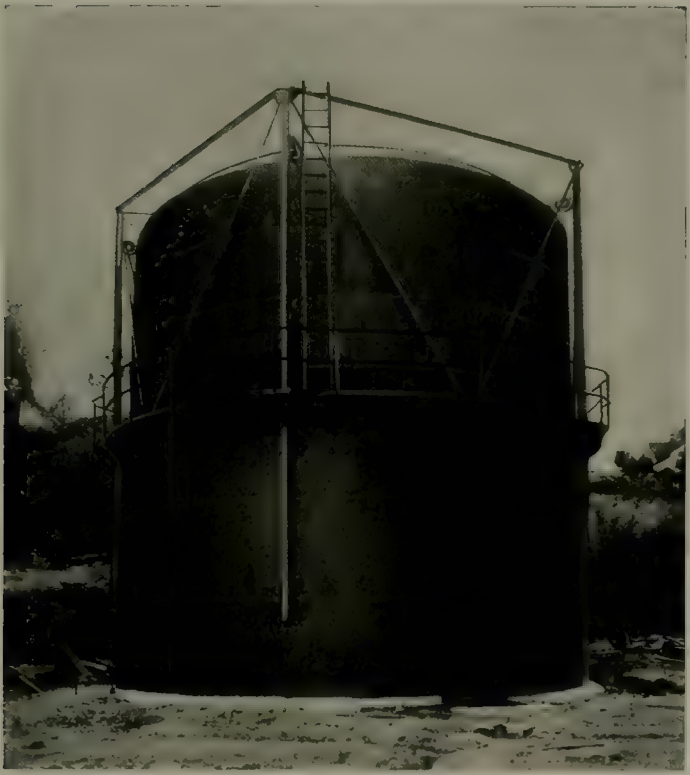


Fig. 131. ALL ARC WELDED GAS HOLDER OF 15,000 CUBIC FEET CAPACITY

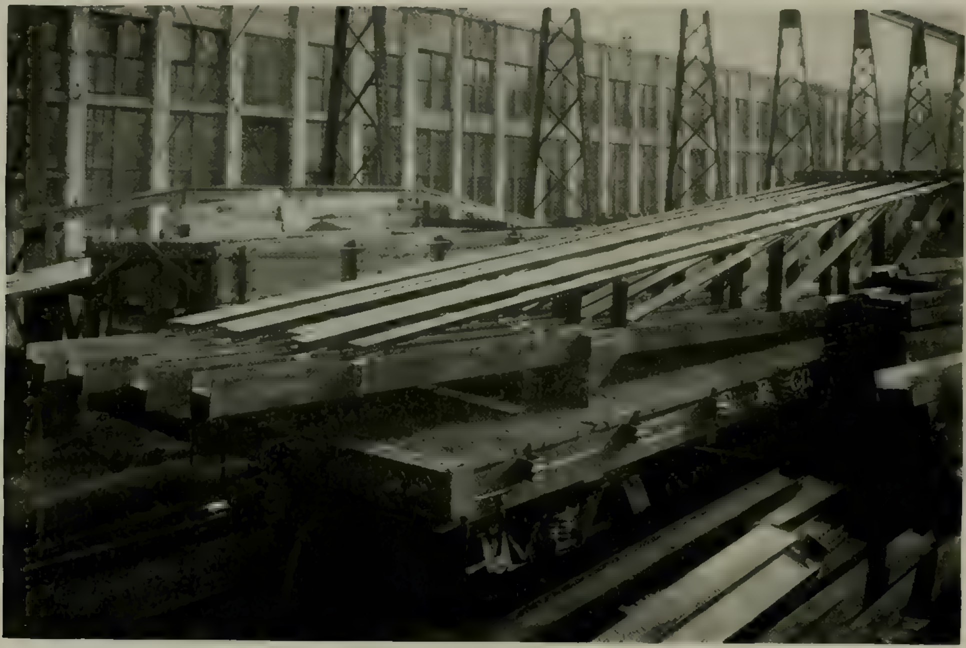


Fig. 132. STRUCTURAL STEEL FRAMES COMPLETELY ARC WELDED

The replacing of rivets by welding in steel frame construction is an application of arc welding which is engaging the attention of structural engineers. Fig. 132 illustrates the extent to which fabrication is possible in the shop before erection. The steel frames are the vertical side frames of the framework shown in Fig. 87. These frames were built in the shop and transported to the scene of erection.

Crane runway brackets were fastened to the side frames in the manner shown by Fig. 133. Note the tack welds.

The top lattice girders in Fig. 87 were built complete in the shop as shown by Fig. 135. Note the small size of the gusset plates and the method of construction of the top and bottom members of the girders.

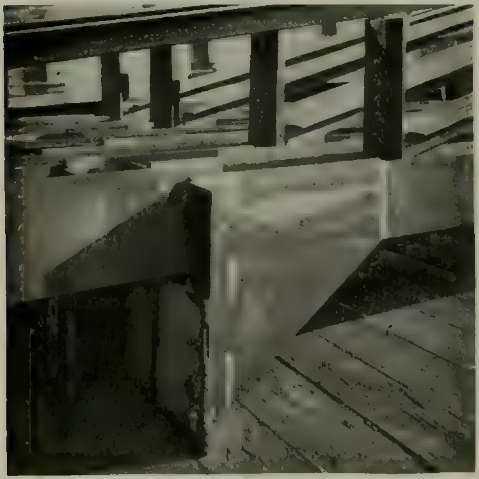


Fig. 133. CLOSE-UP OF CRANE RUNWAY BRACKET ON STEEL FRAMES SHOWN IN FIG. 132

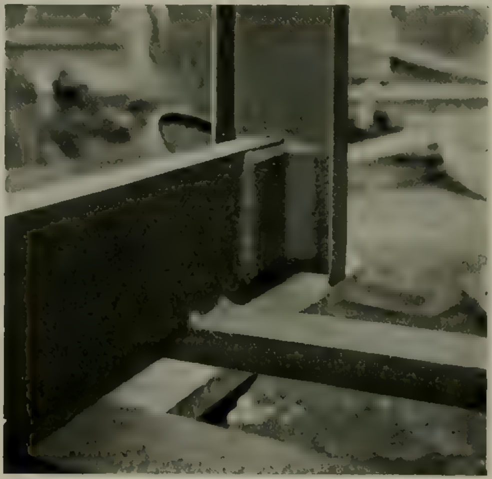


Fig. 134. ARC WELDED STRUCTURAL STEEL JOINT

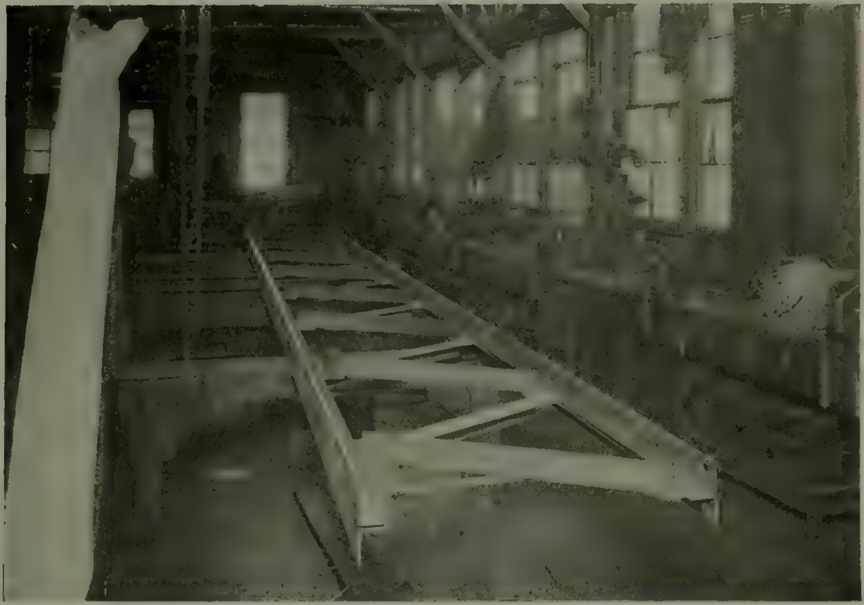


Fig. 135. METHOD OF CONSTRUCTION OF TOP LATTICE GIRDERS IN THE SHOP

Fig. 134 illustrates a method of connecting the webs of two channels together by the use of two short angle sections, one of which does not show in the illustration.

Figs. 136 and 137 show details of a steel framework for an electric sign which is about 22 ft. high with a base about 10 ft. by 30 ft. Note the simplicity of the joint in Fig. 137. It is estimated that a saving of about 20 per cent over the cost of a riveted structure was effected by using arc welding.

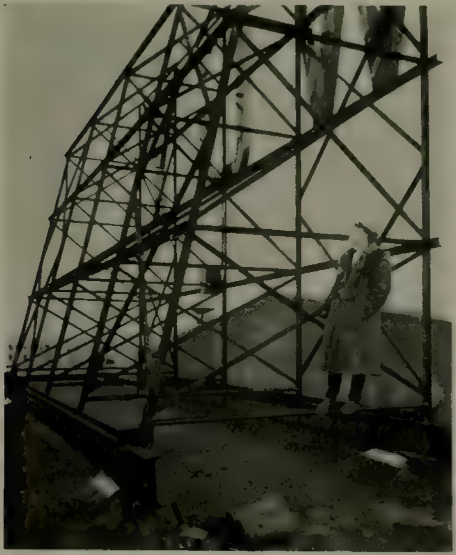


Fig. 136. STRUCTURAL STEEL FRAMEWORK WITH ALL JOINTS ARC WELDED

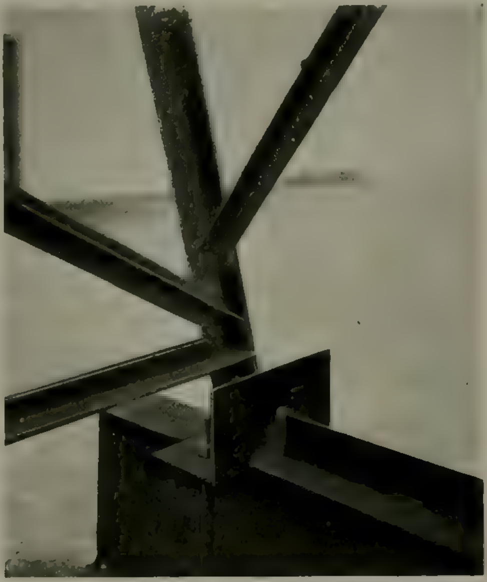


Fig. 137. DETAILS OF A JOINT IN FRAMEWORK SHOWN IN FIG. 136

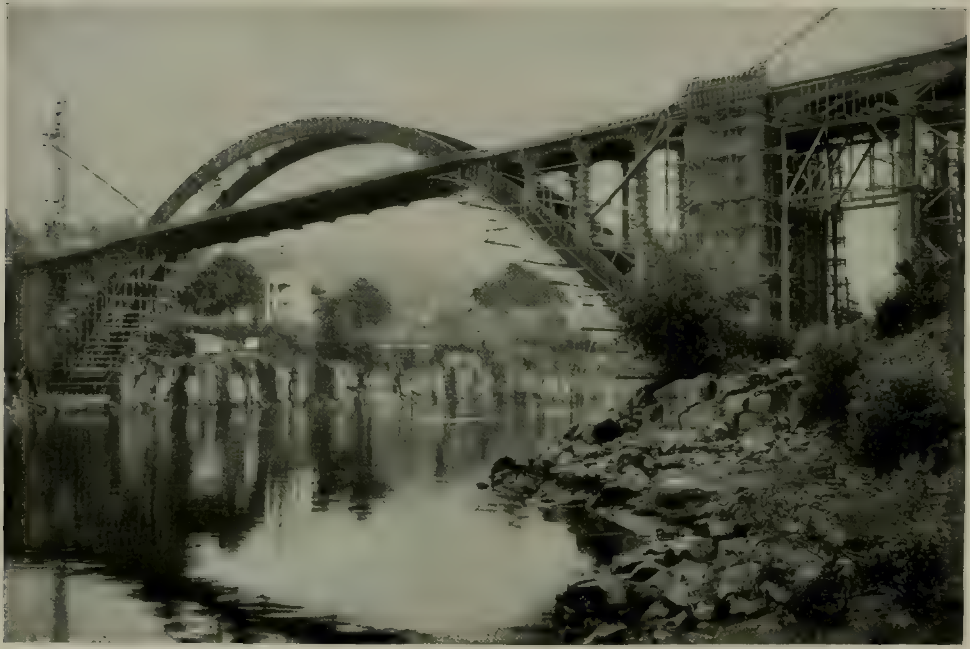


Fig. 138. STEEL BRIDGE WITH REINFORCED CONCRETE CASING. THE ANCHOR RODS FOR HOLDING THE REINFORCED MESH ARE FASTENED TO THE STEEL TRUSSES BY ARC WELDING

In some cases arc welding saves time and expense in reinforced concrete constructions as shown by Fig. 138. The anchor rods for holding the reinforcing mesh for the concrete casing are arc welded to the bridge plates thus saving considerable time, as the punching of numerous holes for tie bolts is thereby avoided. Over 50,000 welds were made on this bridge.

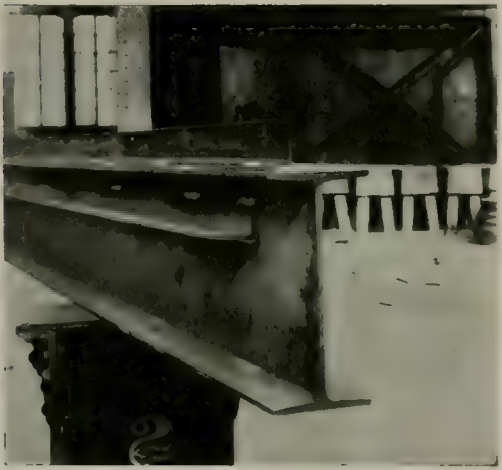


Fig. 139. METHOD OF ATTACHMENT OF ANGLES AND PLATES TO STANDARD I-BEAM

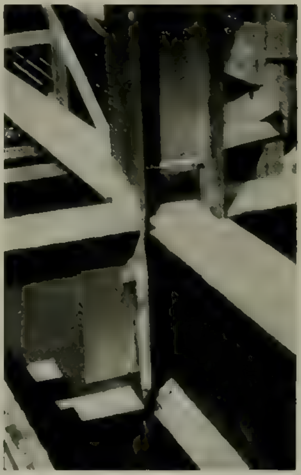


Fig. 140. METHOD OF ATTACHMENT OF FLOOR BEAMS TO VERTICAL MEMBERS

Fig. 141 shows the construction of a two-story building for a garage and automobile salesroom. All joints are arc welded, details of which are shown in Figs. 139 and 140. The bolts were used to line up the members and were left in the finished job. Each joint as shown in Fig. 140 has a designed factor of safety of seven. The building is 150 ft. long and 100 ft. wide and contains 95 tons of structural steel.

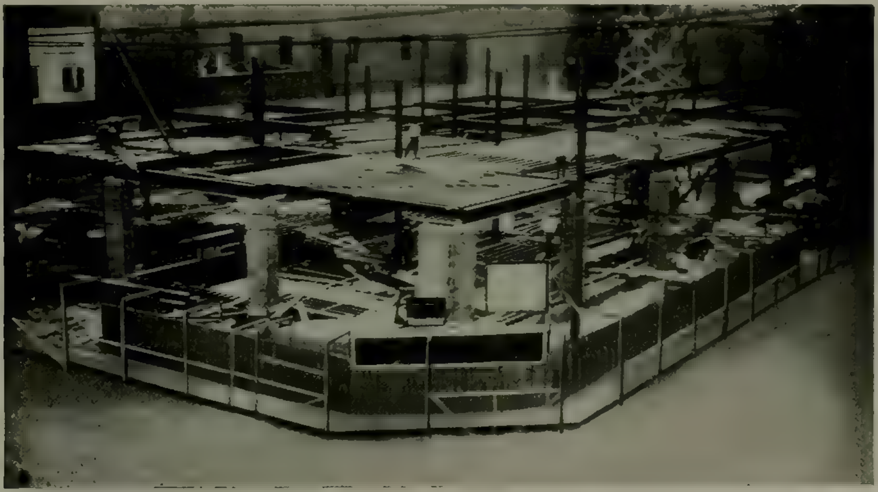


Fig. 141. CONSTRUCTION OF TWO-STORY GARAGE AND SALESROOM BY ARC WELDING

## Pipe Lines

The advent of welded joints into pipe line construction has proved that a welded pipe may be more easily, quickly and cheaply constructed and maintained than any type of pipe with flanged connections. A few examples of arc welded pipe installations follow.

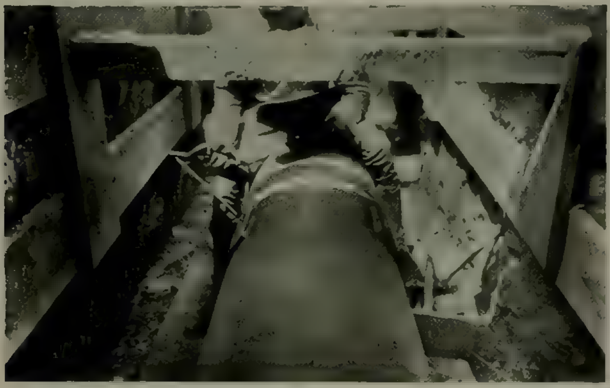


Fig. 142. DETAILS OF ARC WELDED JOINT IN 20-IN. 250-LB. PRESSURE STEAM MAIN

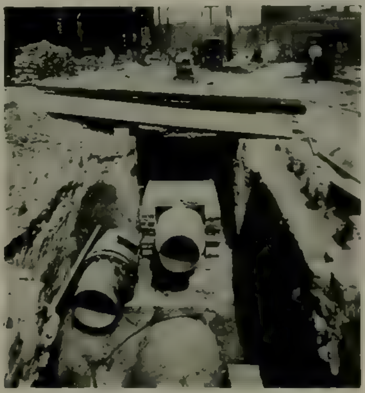


Fig. 143. DETAILS OF EXPANSION JOINT AND CONNECTIONS IN 20-IN. 250-LB. PRESSURE STEAM MAIN

Figs. 142 and 143 show a welded 20-in. steam main for 250-lb. steam pressure. Fig. 142 shows the type of joint used. Fig. 143 shows the conduit and covering with which the pipe was laid. This illustration shows an expansion joint at one side of the trench just

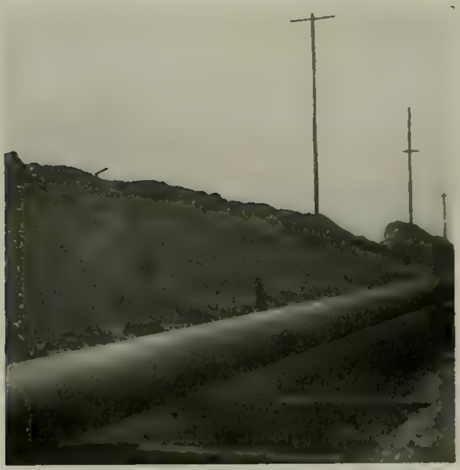


Fig. 144. TEN-INCH ARC WELDED OIL PIPE LINE

prior to connecting it to the pipe line. The welded line was tested in sections to 500-lb. hydraulic and hammer test without a leak. The expansion joints were of the Duplex sleeve type and were spaced from 120 ft. to 160 ft. apart.

In Fig. 144 is shown a 10-in. oil pipe line with all joints made by arc welding.

Fig. 145 shows another installation of arc welded pipe. Note the appearance of the finished weld in the illustration at the left.

An example of both circumferential and longitudinal pipe seams is given in Fig. 146. Note the lugs welded onto the ends of the sections of pipe to facilitate construction in the field. The expansion joints are well illustrated.

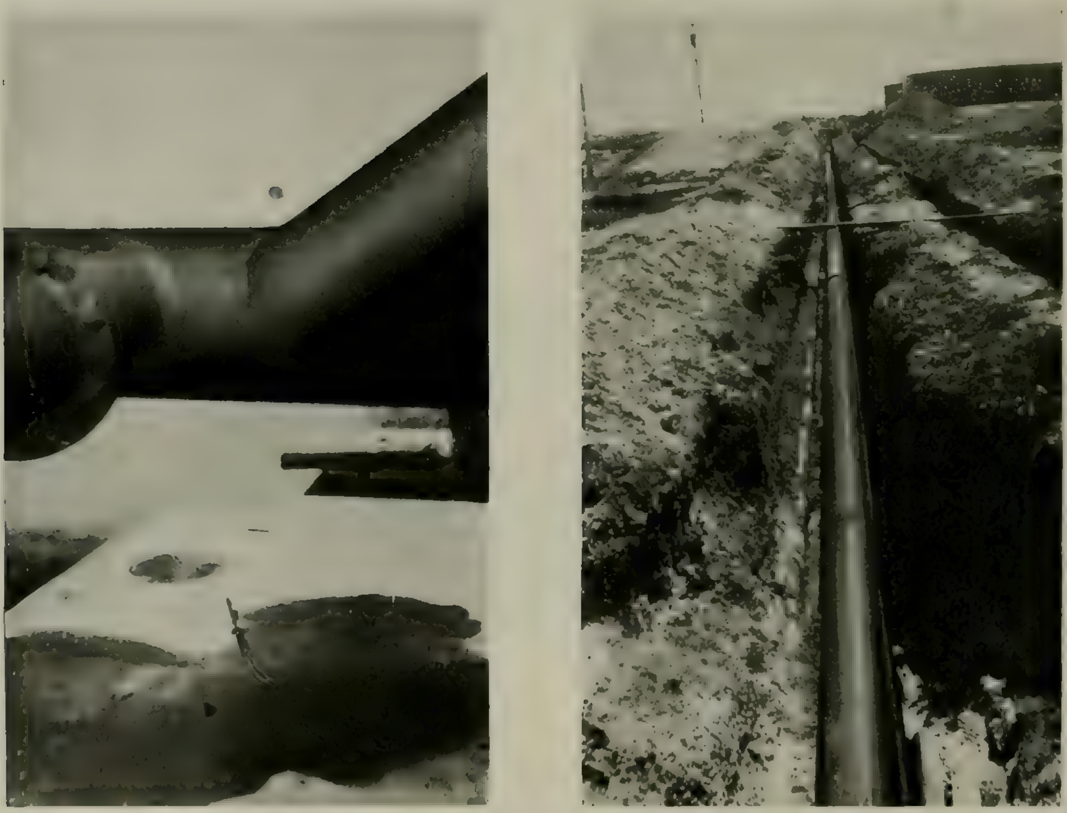


Fig. 145. TEN-INCH OIL PIPE LINE AND 12-INCH HEADER WITH ARC WELDED JOINTS

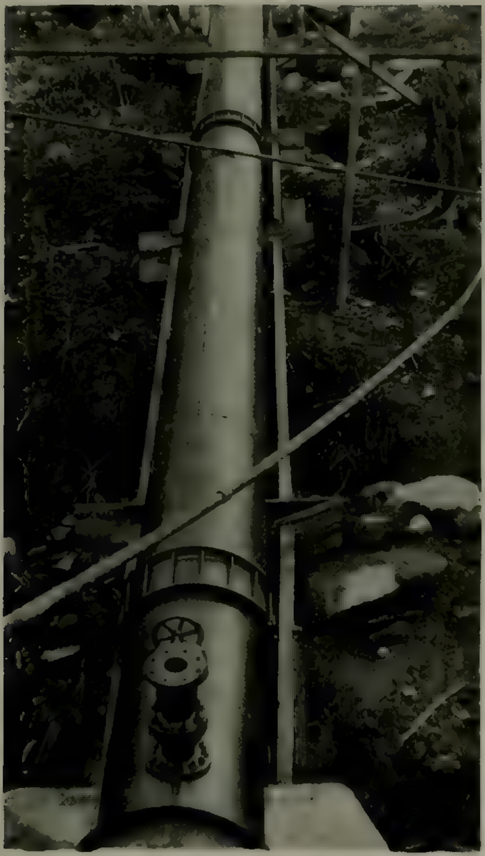


Fig. 146. PIPE LINE WITH ARC WELDED CIRCUMFERENTIAL AND LONGITUDINAL SEAMS

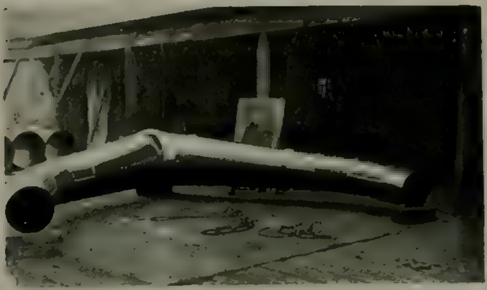


Fig. 147. SECTION OF ARC WELDED PIPE OF SPECIAL SHAPE

The use of arc welded joints gives a great freedom in the construction of special shapes and connections as shown by Fig. 147. Also, great savings in weight and cost of fittings are secured by arc welded construction as against castings. Note the construction of the longitudinal seams and the lugs on the circumferential seams similar to those shown in Fig. 146.

Fig. 148 illustrates a type of joint in an arc welded pipe line. This line is 3574 ft. long and was tested by 550-lb. hydraulic pressure. This pipe line operates with a pressure of 150 to 250 lb. for 24 hours per day.

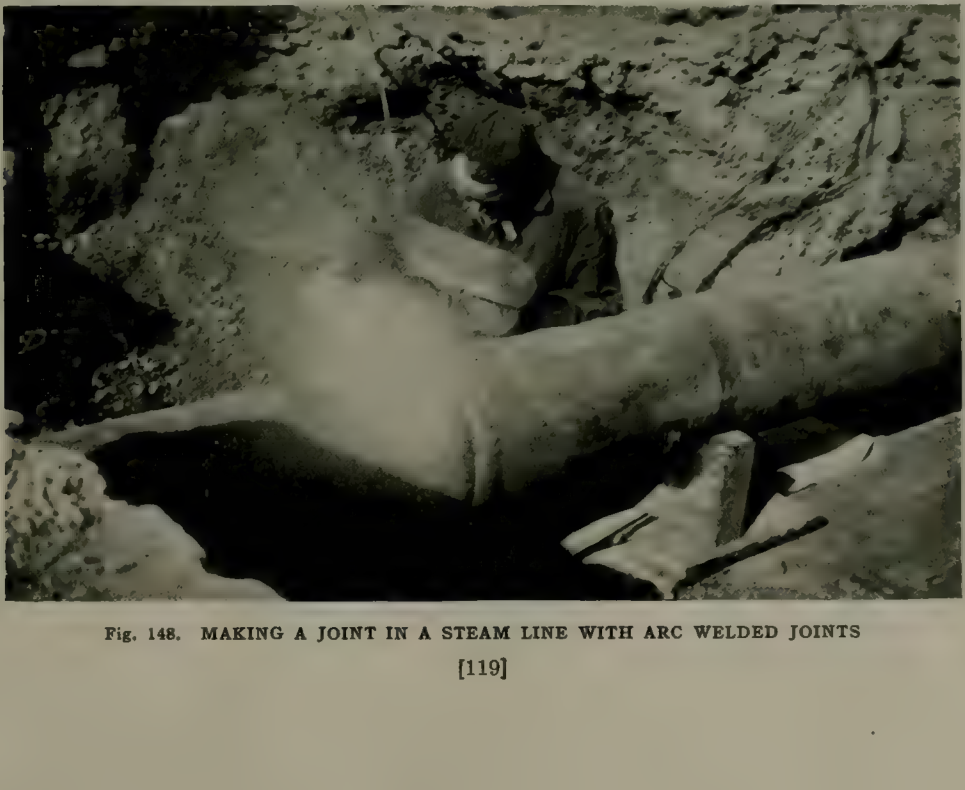


Fig. 148. MAKING A JOINT IN A STEAM LINE WITH ARC WELDED JOINTS

The varied types of work to which arc welding may be successfully applied are illustrated on this page. The automatic welder may be easily applied to welding longitudinal pipe seams. An example of this is shown in Fig. 149. These pipe sections are welded in the machine shown in Fig. 152 and then the flanges are welded on. This pipe is used in gas plants for connections between generators, superheaters and storage tanks. Some of the special pipe fittings and connections are shown in Fig. 150. Fittings for this size of pipe are much easier and simpler to make and are cheaper than by any other process. Fig. 151 shows an arc welded washer cooler tower and piping installed in a gas plant.

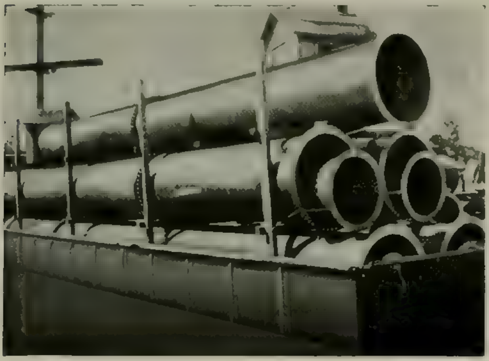


Fig. 149. AUTOMATICALLY ARC WELDED STEEL PIPING

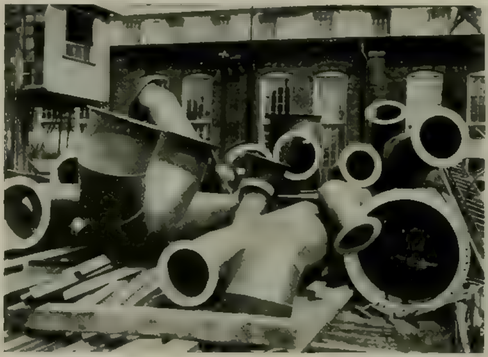


Fig. 150. ARC WELDED MISCELLANEOUS PIPE FITTINGS READY FOR SHIPMENT FROM THE FACTORY

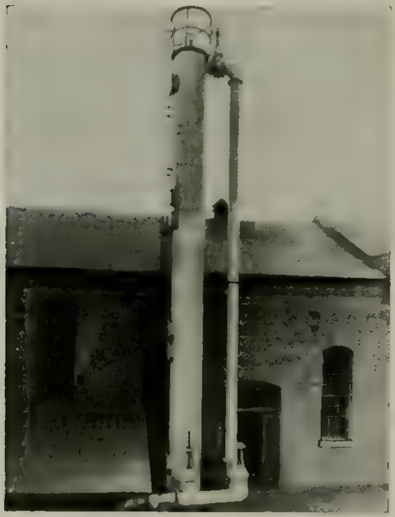


Fig. 151. ARC WELDED WASHER COOLER TOWER AND PIPING

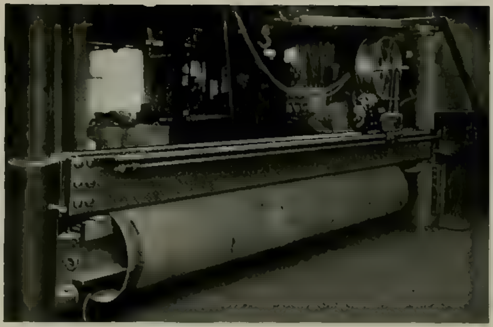


Fig. 152. AUTOMATIC ARC WELDING MACHINE WELDING PIPE SHOWN IN FIG. 149

The flexibility allowed by the use of the electric welding arc in the construction of pipe connections is illustrated by Figs. 153 to 156 inclusive. Figs. 153 and 154 show an arc welded blast pipe and an intensive scrubber by-pass pipe, respectively, for a gas generating station.

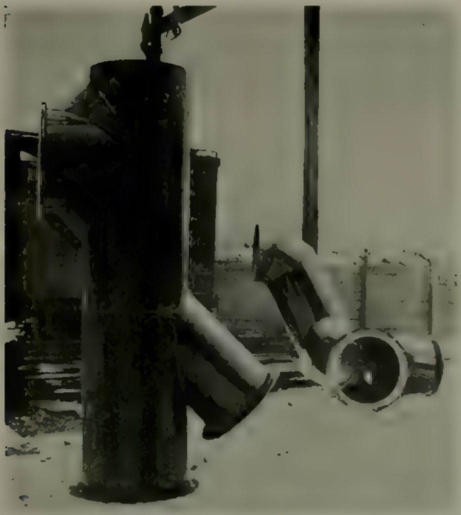


**Fig. 153.** ARC WELDED BLAST PIPE CONNECTION FOR GAS STATION

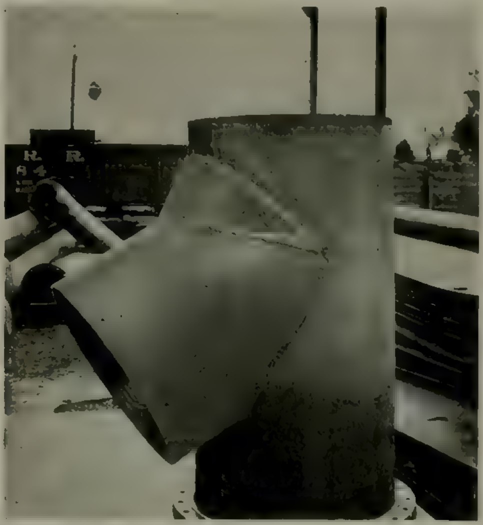


**Fig. 154.** ARC WELDED INTENSIVE SCRUBBER BY-PASS PIPE FOR GAS STATION

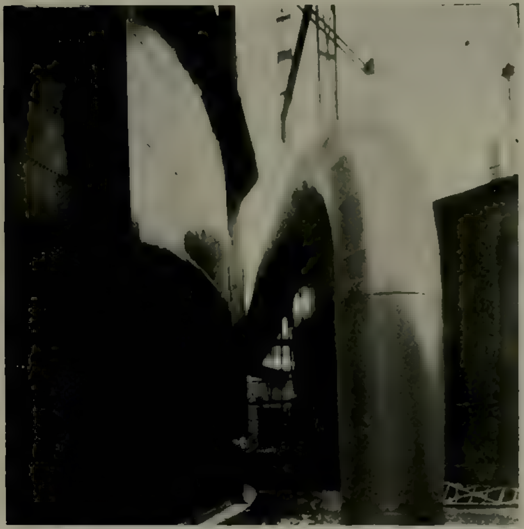


**Fig. 155.** ARC WELDED 48-IN. INLET PIPE TO RELIEF HOLDER IN A GAS GENERATING STATION

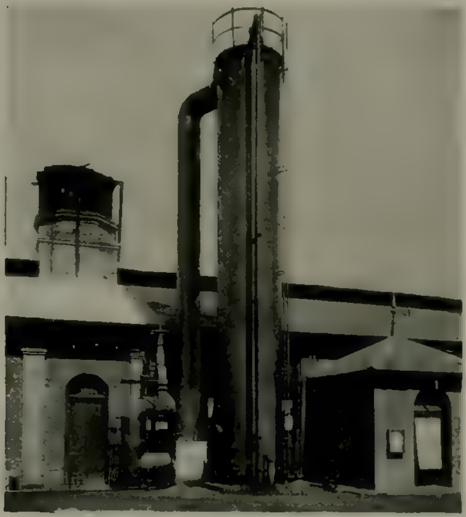


**Fig. 156.** ARC WELDED WASHER COOLER AND PIPING

Fig. 155 shows a welded inlet pipe to relief holder in a gas plant. This pipe is 48 in. in diameter. Fig. 156 shows an arc welded washer cooler. The ladder on the side of the cooler has welded rungs.

Where flanged joints are necessary considerable economy may be effected by arc welding the flanges to the pipe as shown by Fig. 157. The flange is ¼-in. plate and the pipe is $\frac{1}{16}$-in. steel.

Water-tight joints as shown in Fig. 158 are easily and quickly made by arc welding.

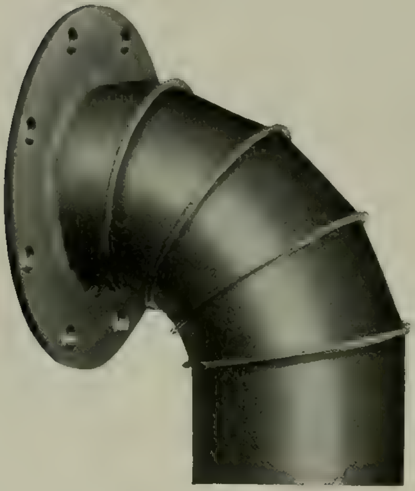


Fig. 157. FLANGE ARC WELDED TO PIPE

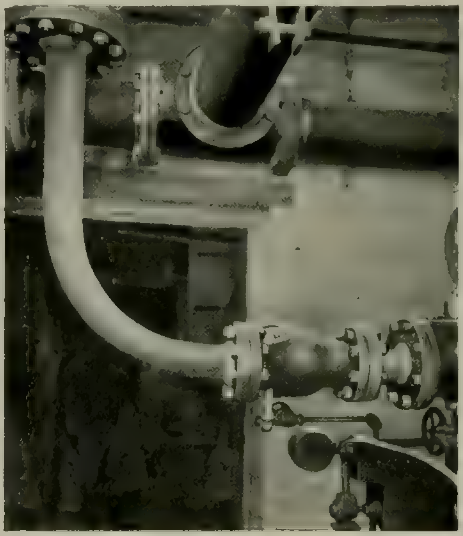


Fig. 158. METHOD OF MAKING STEAM AND WATER TIGHT JOINTS

## Shipbuilding

Considerable attention was directed during the latter years of the war toward the possibilities offered by arc welding in ship construction. A very complete report of the present state of the art with regard to the shipbuilding industry is printed in serial form in *Marine Engineering*, beginning with the August, 1923, issue. This report was prepared by Mr. E. H. Ewertz and has been reprinted by the American Bureau of Welding in bulletin form.

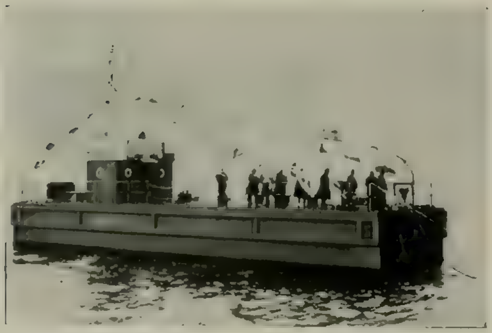


Fig. 159. OIL BARGE BUILT ENTIRELY BY USING ELECTRIC ARC WELDING FOR JOINING THE PLATES

Fig. 160. LAYING THE KEEL FOR OIL BARGE SHOWN IN IN FIG. 159

There are numerous opportunities to utilize the advantages of the electric arc welding process in the construction of new ships. Mr. Ewertz in his article has pointed these out and has even worked up a complete design for an arc welded boat. This design by Mr. Ewertz embodies some very unusual and new ideas.

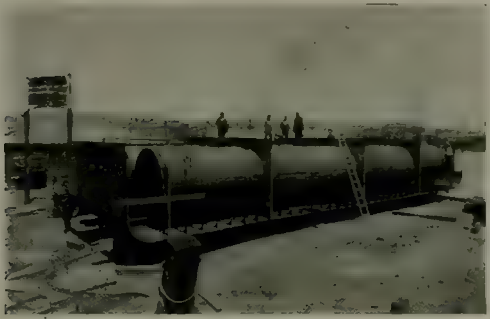


Fig. 161. ERECTING CROSS BULKHEADS ON OIL BARGE SHOWN IN FIG. 159

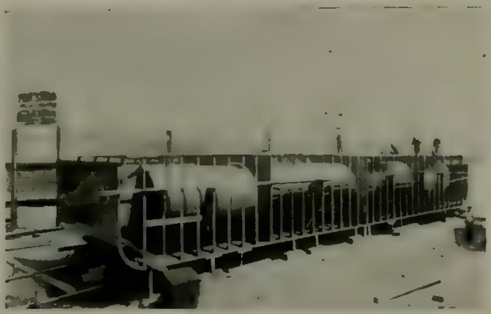


Fig. 162. ERECTING SIDE FRAMEWORK OF OIL BARGE SHOWN IN FIG. 159

In the summer of 1924 an all welded oil barge was built at Providence, R. I. The hull was 76 ft. long, 21 ft. wide, and 11 ft. in depth and was built of $\frac{3}{16}$-in. plates lapped 6 in. and welded on both laps. Fig. 159 shows the boat after launching. Figs. 160, 161, and 162 show different stages of the construction. There are 87 tons of material in the boat. It was built by three welders and three mechanics as a maximum. The actual working time required was three months, although a total of five months was required due to weather interruptions and other work. Actually, the boat was built by two welders, as the third welder was not available for a large portion of the time. The capacity of the two tanks shown in Fig. 161 is 52,000 gallons.

### Automobile Industry

Competition in the automobile industry has been responsible for many changes in methods of production since automobiles were first manufactured. Automatic machines have in many cases replaced manual labor and production has been increased. Within the last few years electric arc welding has been gradually becoming regarded as a very valuable process for simplifying production methods and cutting costs. One of the most extensive applications for welding in this field has been that of rear axle housings. Automatic arc welding machines have been applied and found to be very successful. The elimination of oil leakage and loose bolts or nuts are two of the great advantages of welded housings. Welding is also used extensively for welding universal joints to drive shafts, joints in steel bodies, automobile frames, etc.

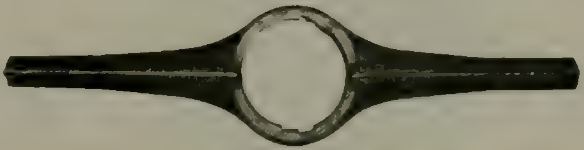


Fig. 163. ARC WELDED AUTOMOBILE REAR AXLE HOUSING

Rear axle housings for automobiles are now commonly made of two pressed steel halves arc welded together as shown by Fig. 163.

## Repair Shops and Garages

The opportunities afforded for the use of arc welding in this field are very numerous. The process is now being used in many instances to salvage parts which otherwise must be scrapped. A few examples of general applications follow.

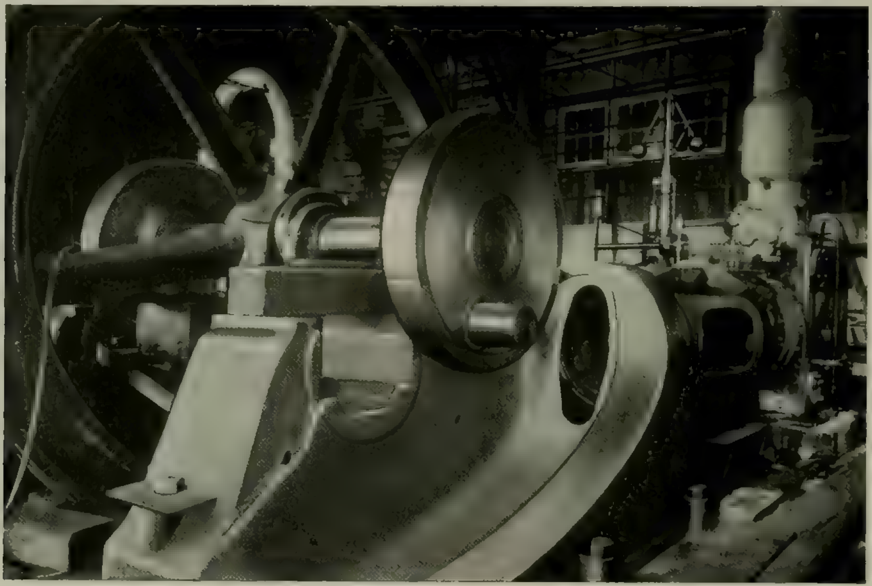


Fig. 164. CAST IRON FRAME OF 400-H.P. AMMONIA COMPRESSOR WITH BREAK PREPARED FOR REPAIR BY ARC WELDING

An example of the use to which electric arc welding may be put for repairs to machine parts is shown in Fig. 164. This cast iron frame was welded with a special electrode. The machine is a 400 horse power ammonia compressor.

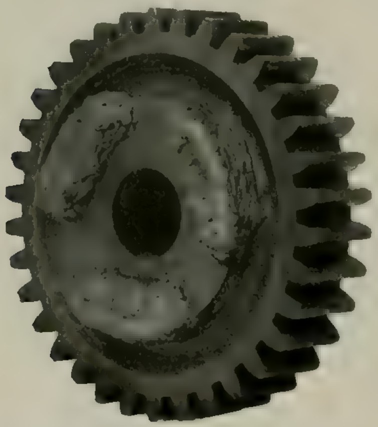


Fig. 165. NEW BOSSES BUILT ON CAST IRON DRIVE GEAR (BEFORE MACHINING)

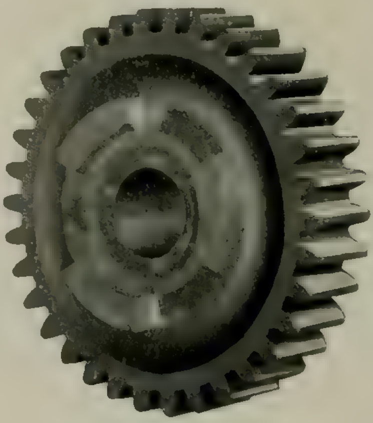


Fig. 166. NEW BOSSES BUILT ON CAST IRON DRIVE GEAR (AFTER MACHINING)

Arc welding is of material assistance in the repair of gears as shown by Figs. 165, 166 and 167. Figs. 165 and 166 show rebuilt lugs on a cast iron driving gear for a testing machine. The bosses had been broken in service and were rebuilt using two ⅜-in. steel studs in each boss. Fig. 167 shows the repair of automobile gears with new teeth built up by the arc welding process.

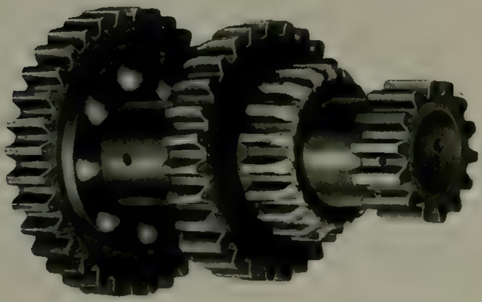


Fig. 167. AUTOMOBILE GEARS WITH NEW TEETH BUILT BY ARC WELDING

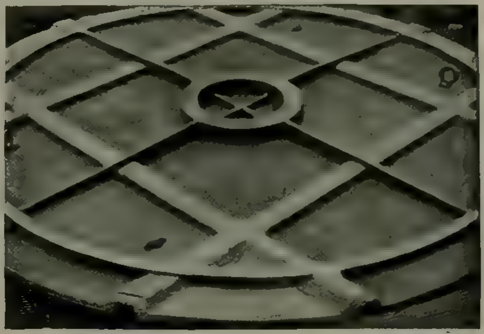


Fig. 168. CAST IRON TURNTABLE REPAIRED BY ARC WELDING

The repair of large castings is possible with the arc welding process although in such cases the effect of the heat produced by the arc requires the utmost attention. Fig. 168 shows the repair of a large cast iron turntable.

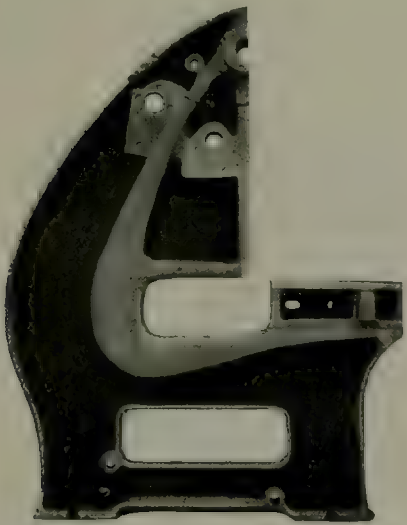


Fig. 169. SIDE VIEW OF BROKEN SHEAR HOUSING REPAIRED BY ELECTRIC ARC WELDING

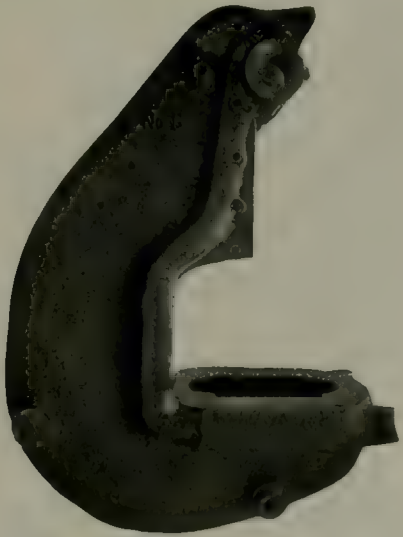


Fig. 170. SIDE VIEW OF REPAIR OF PUNCH PRESS

Fig. 169 shows the repair of a large shear housing by the arc process. Fig. 170 shows the repair of a punch press frame.

Figs. 171 and 172 illustrate the practical application of arc welding to automobile frames. Fig. 171 shows the frame channel on the right side of the car cracked from the bottom about two-thirds of its width. The angle iron and bolts shown were used in making a temporary repair which enabled the car to be run to the shop under its own power. The frame was first jacked up until the track was tightly closed, then a single bead weld was run along the entire length of the crack on the outside and bottom of the channel. Next, a 3/16-in. steel plate 8 in. by 2 in. was welded over the crack as shown in Fig. 172. A 5/32-in. electrode with about 170 amperes and 20 volts was used to make the weld. Approximately half an hour was required for the complete repair which was accomplished with no disassembly of the car other than the removal of the right running board.

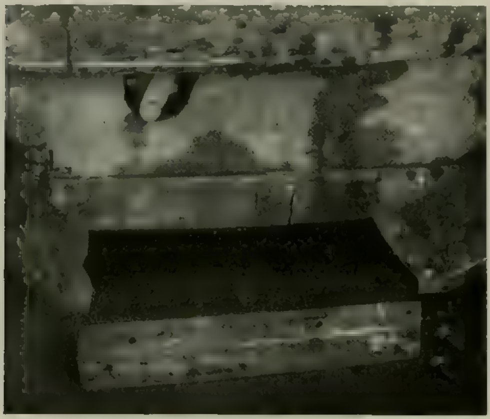


Fig. 171. BREAK IN CHANNEL FRAME OF AUTOMOBILE BEFORE WELDING

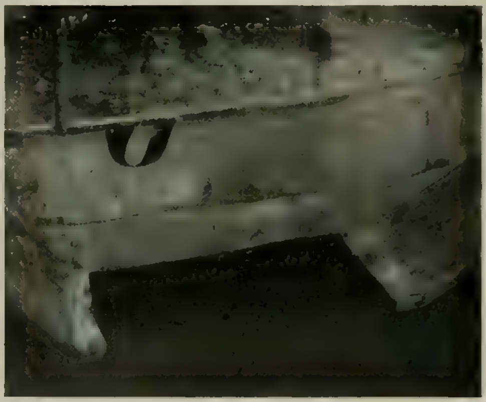


Fig. 172. REPAIR OF BREAK SHOWN IN FIG. 171. AFTER WELDING

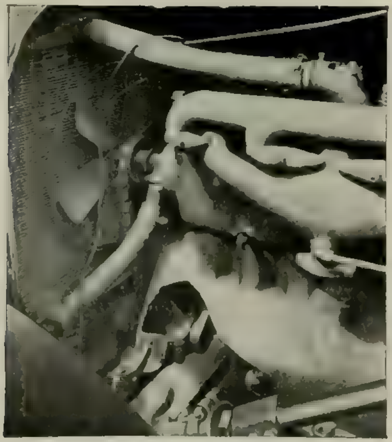


Fig. 173. BROKEN AUTOMOBILE CRANK CASE

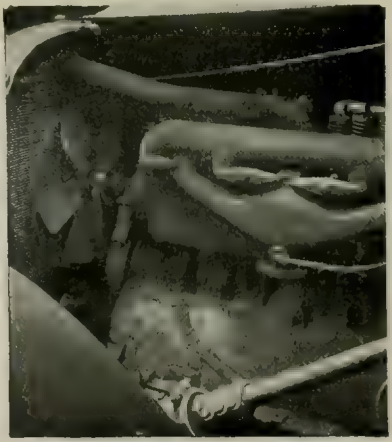


Fig. 174. CRANK CASE OF FIG. 173 SHOWING REPAIR COMPLETED BY ARC WELDING

Figs. 173 and 174 show the repair of a broken crank case of an automobile. The engine was not dismantled and the time required to make the repair was less than an hour.

The repair of a large cast iron water turbine runner is shown in Fig. 175. Holes worn in the blades by the erosive action of the water were patched and the surface ground smooth so that the finished weld could hardly be distinguished from the blade itself.

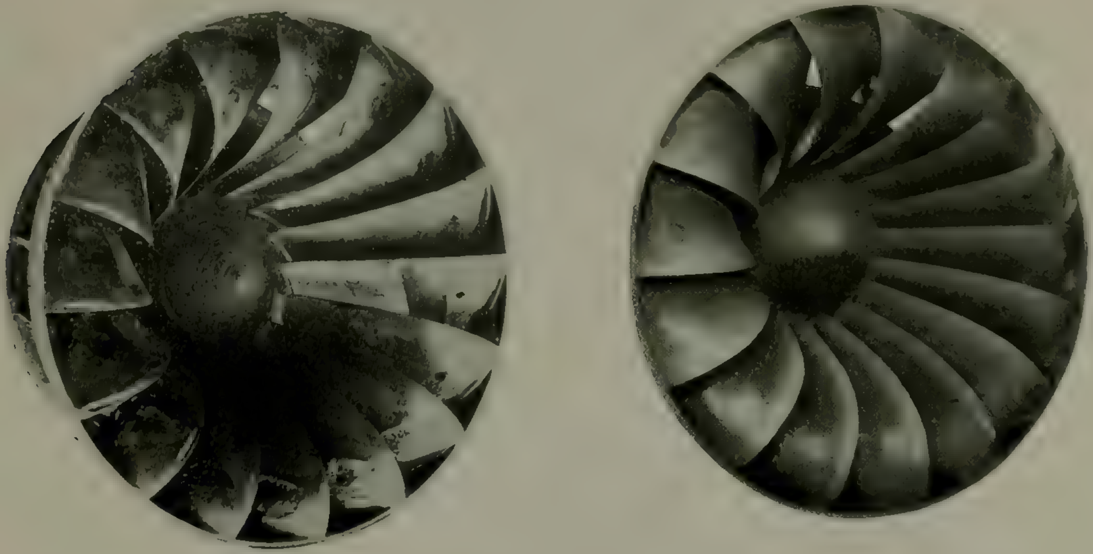


Fig. 175. CAST IRON WATER TURBINE RUNNER REPAIRED BY THE ELECTRIC ARC PROCESS

## Miscellaneous

The greatest advantage which is to be gained by using arc welding is its adaptability to such a variety of applications at a very low cost without the necessity of large and expensive machinery. In the steel and metal industry today the arc welding process is becoming recognized as a very efficient and valuable aid in cutting production costs and simplifying manufacturing processes on miscellaneous or special jobs. Oftentimes the design of the product must be changed or can be changed and by this change eliminate some of the operations which were formerly necessary. In some cases a sturdier product is the result.

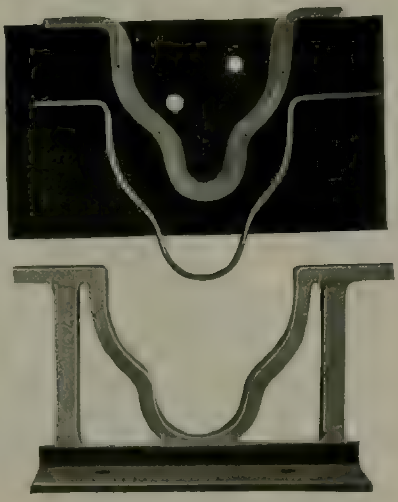


Fig. 176. ARC WELDED DIE

The examples shown here possess certain advantages over former methods of production which may be listed as follows:

Welded seams make dust-tight joints.

Welded construction is rigid and firm, giving long life.

Smooth connections make for smooth outward appearance.

Welding eliminates various preliminary operations and thereby cuts costs.

Fig. 176 shows the extent to which arc welding is used in making dies for forming steel parts in a bulldozer.

Fig. 177 shows how the electric arc welding process helps in the manufacture of ice cream cans. The longitudinal seam is welded at the rate of 60 inches per minute with a more solid and dependable joint than the old soldering process can give.

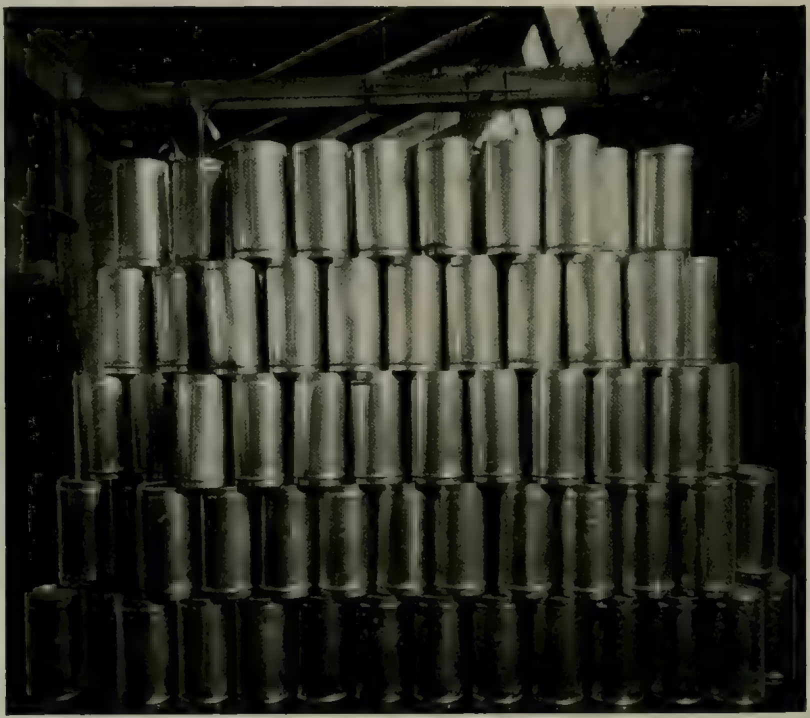


Fig. 177. ONE HOUR'S PRODUCTION (103) OF ICE CREAM CANS WELDED WITH THE ELECTRIC ARC

One great advantage of the welded joint, besides the speed with which it can be made, is its durability when tinning the can. After a certain length of service the tinning wears off and the can must be retinned. The heat of the retinning operation will destroy the soldered joint, after which the joint must be resoldered. The welded seam is not affected by the tinning process and is easily coated.

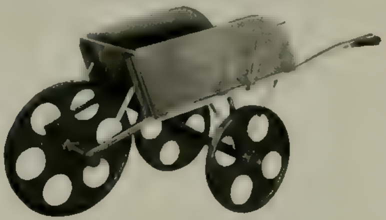


Fig. 178. ALL ELECTRIC ARC WELDED STEEL WHEELBARROW

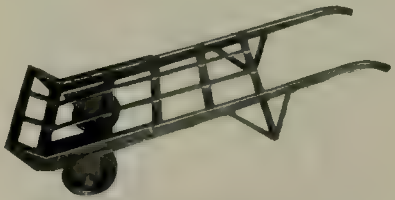


Fig. 179. ALL ELECTRIC ARC WELDED STEEL TRUCK

Besides the lower first cost of arc welding as compared to other processes, the neat appearance of the welded job is often quite marked. This is illustrated by Figs. 178 and 179.

Fig. 178 shows a completely arc welded steel wheelbarrow which is rapidly replacing the older types of wood wheelbarrow. This type of construction lasts longer and will stand more severe usage than the wooden type.

Fig. 179 shows a completely arc welded hand truck.

Fig. 180 shows a small welded truck which combines strength and lightness in its makeup. Standard structural parts are used and no extensive preparation is necessary for the welding operation.

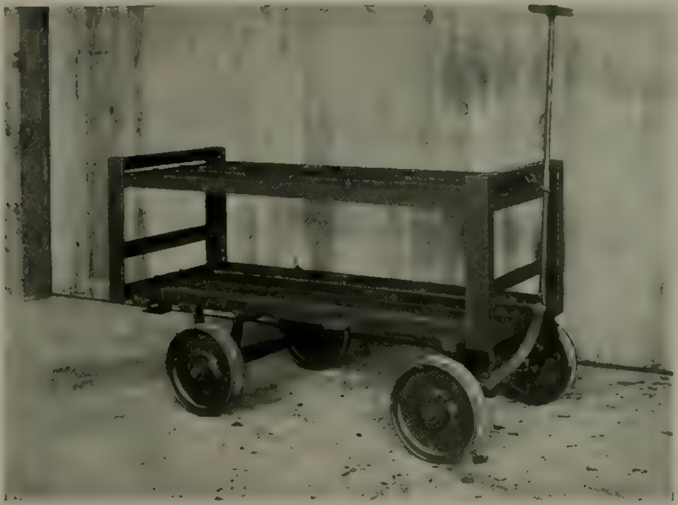


Fig. 180. STEEL TRUCK FABRICATED BY THE ELECTRIC ARC WELDING PROCESS

Fig. 181 shows a steel locker built without rivets using the electric arc to join the parts. No specially formed parts were used in this fabrication as the material is ⅛-in. sheet steel. The total cost of fabrication by welding is about $28 while the cost of building the locker, if riveted, would be about $68. The welded locker requires about half the time to construct is dust-tight and solid, and considerably lighter than the riveted type.

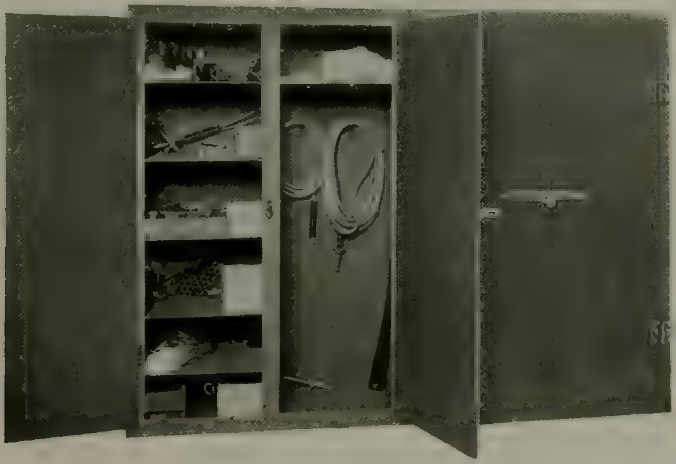


Fig. 181. STEEL LOCKERS ASSEMBLED BY ELECTRIC ARC WELDING IN THE G-E WELDING SCHOOL

Steel ladders, shop stools, small steel cabinets, and various other steel articles which find use about a manufacturing plant, are easily, quickly, simply, and cheaply made with the electric welding arc. It is the metal worker's needle and thread, a universal saver of labor, time, material, and cost.

# PART IV

# G-E WELDING APPARATUS

## GENERATING EQUIPMENT

In order to do successful arc welding some supply source is required which will furnish a uniform flow of electrical energy to the welding arc. This energy flow must be constant for best results and the welding apparatus must be so designed and must so operate that it will not be affected by the irregularities of the welding arc caused by the slight unsteadiness of the operator's hand or possible uneven melting of the electrode material.

The General Electric Company has developed and manufactures a complete line of motor-generator sets for this work.

### Single Operator, Constant Energy Type

These machines are known as Types WD-11, WD-12 and WD-14. Their rated capacities are as follows:

| Type | Continuous | One Hour |
|---|---|---|
| WD-11 | 150 amperes at 25 volts | 200 amperes at 25 volts |
| WD-12 | 200 amperes at 25 volts | 250 amperes at 25 volts |
| WD-14 | 300 amperes at 25 volts | 400 amperes at 25 volts |

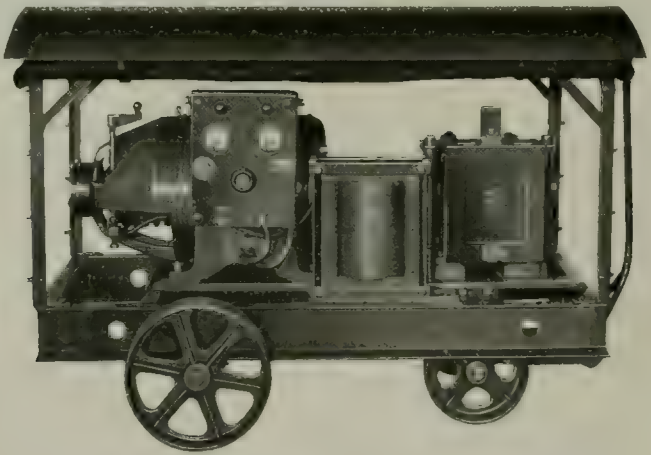


Fig. 182. PORTABLE TYPE WD-12 ARC WELDING SET WITH PROTECTIVE CANOPY AND CURTAINS FOR PROTECTION FROM THE WEATHER AND DUST

Fig. 182 shows the portable Type WD-12 with protective canopy for protection from dust and the weather. The entire apparatus is mounted on a welded structural steel base as a unit. Fig. 183 shows a rear view of this welding set without the canopy.

In some cases it is necessary and desirable to drive the welding generator by a gas engine instead of an electric motor. Fig. 184 shows the Type WD-12 welding set with a Buda 4-cylinder gasoline engine.

This type of generator is equipped with a device for shifting the brushes to obtain current adjustment. In this way the exact amount of current desired may be obtained by simply turning the hand.

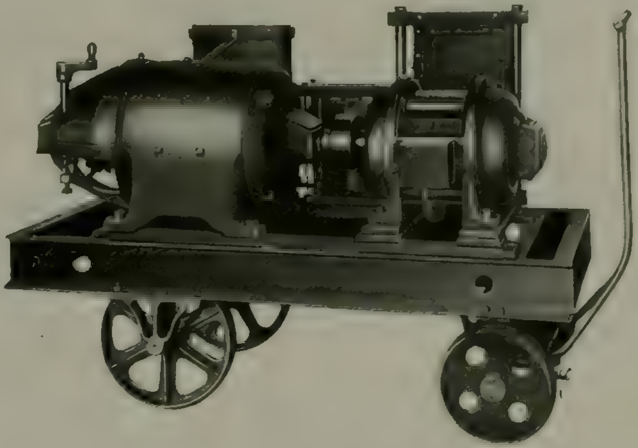


Fig. 183. REAR VIEW OF PORTABLE TYPE WD-12 ARC WELDING SET

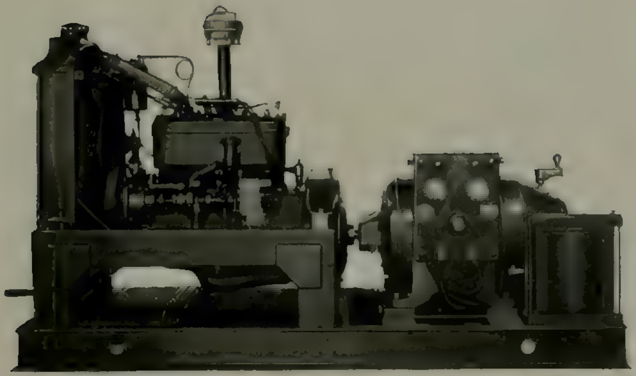


Fig. 184. TYPE WD-12 ARC WELDING SET WITH BUDA GASOLINE ENGINE

**Multiple Operator, Constant Potential Type**

These machines are low voltage (60 volts), self-excited, compound wound, and designed to deliver constant voltage to the arc. The welding current is regulated to the proper value for the job by means of low voltage resistors in series with the arc. These machines are built in the following sizes:

400, 500, 750, 1000, 1500, 2000 amperes for one hour.

The 400-ampere set is shown in Fig. 185. The resistors and current regulating switches are plainly shown. This machine is completely mounted on a welded structural steel base as a unit.

With the resistor combination shown, two operators may draw up to 200 amperes each, or one operator up to 400 amperes for metallic welding. For carbon welding up to 400 amperes may be drawn by one operator.

For the larger sets the motor-generator set is mounted as a unit and the motor starter and welding control equipment are mounted separately as shown in Fig. 186.

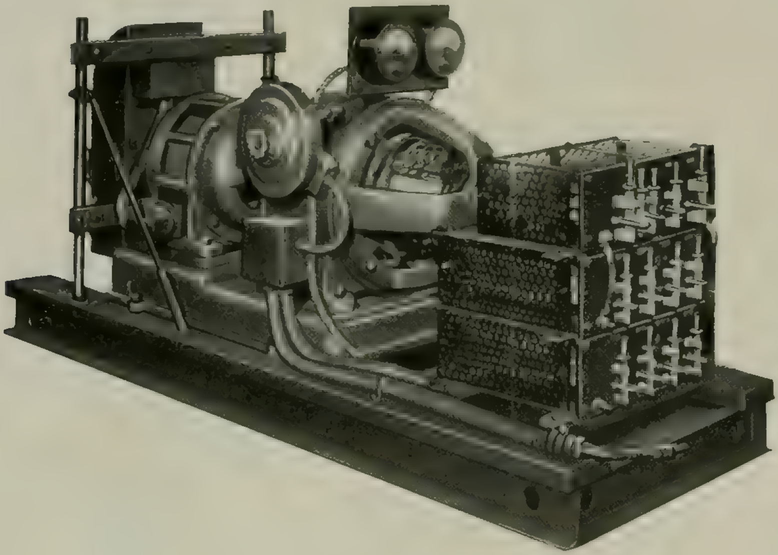


Fig. 185. CONSTANT POTENTIAL 400-AMPERE ARC WELDING SET

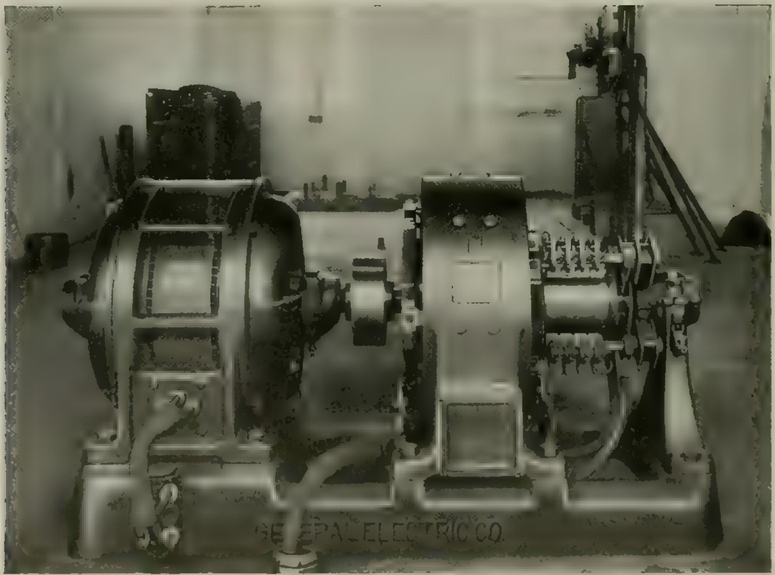


Fig. 186. STATIONARY CONSTANT POTENTIAL 500-AMPERE ARC WELDING SET AND CONTROL

## Resistor Arc Welders

For certain kinds of repair and maintenance work, the resistor type of welder is desired on account of its lightness and portability. On street railway lines and for mine service these welders are adapted for arc welding.

These resistor arc welders are built in the following sizes:

| Volts | Max. Amperes | Weight in Lb. (complete) |
|---|---|---|
| 400/650 | 200-300 | 180 |
| 400/650 | 150-200 | 200 |
| 200/275 | 60-200 | 65 |

Fig. 187 shows the first resistor listed in the table above.

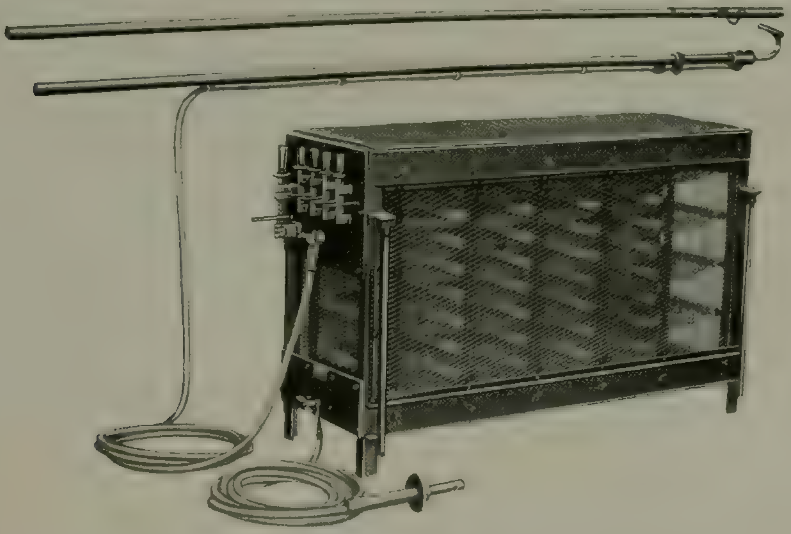


Fig. 187. TYPE AW, FORM A, 400/600-VOLT ARC WELDING RESISTOR

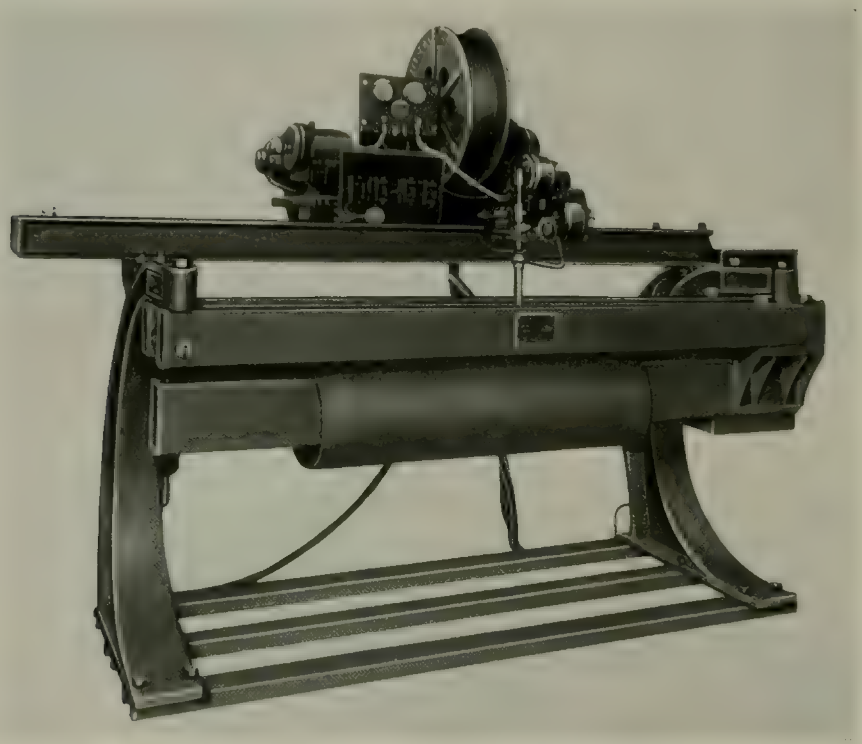
## AUTOMATIC ARC WELDING EQUIPMENT

In order to perform by an automatic device, the process of welding by means of an electric arc and a metallic electrode, an equipment is required which will first touch the electrode to the work and then quickly withdraw it, thus starting the arc, and which will thereafter maintain a constant length of arc by feeding the electrode wire to the weld at the proper speed to replace the metal of the wire which is melted away and deposited in the weld. The General Electric Company has developed apparatus which will not only automatically perform these required functions, but which will perform rapidly and with a greater degree of precision and exactness than is possible of attainment by even the most expert of operators when welding by hand.

A complete equipment consists of the following:

Welding head
Travel carriage or other travel mechanism
Control panel
Clamping device
Motor-generator set for power supply.

The General Electric Company has developed various complete machines for welding tanks and pipe as shown by the following illustrations.



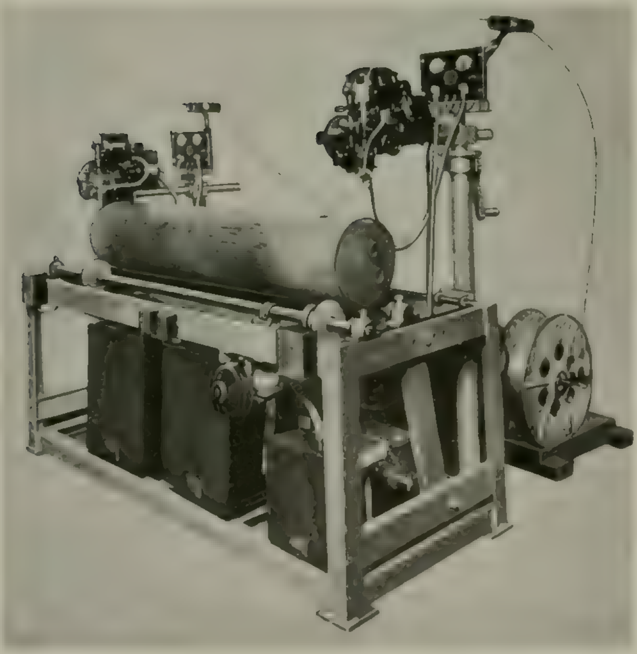


Fig. 188. (ABOVE) AUTOMATIC ARC WELDER FOR SIDE SEAMS OF RANGE BOILERS AND SMALL TANKS

Fig. 189. (LEFT) AUTOMATIC ARC WELDER FOR CIRCULAR SEAMS OF RANGE BOILERS AND SMALL TANKS

Fig. 188 shows a side seam welder for range boiler and small tanks. This machine consists of a welding head, travel carriage, control panel, and clamping device. The motor-generator set is not shown.

Fig. 189 shows a circular seam welder for range boilers and small tanks. This machine consists of two welding heads, as shown, mounted on vertical supports, a rolling device, control panels and necessary push buttons.

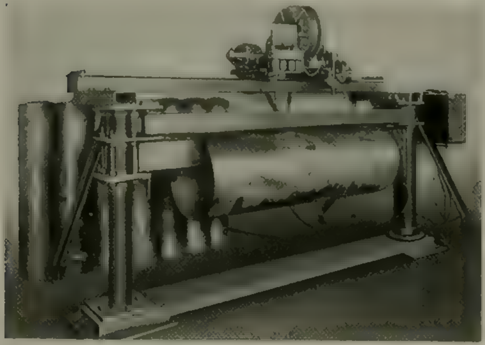


Fig. 190. AUTOMATIC ARC WELDER FOR SIDE SEAMS OF TANKS UP TO 7 FT.

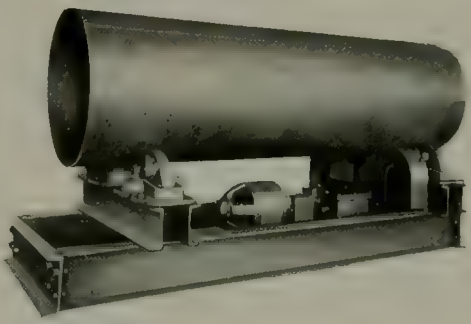


Fig. 191. TANK ROLLING MECHANISM FOR TANKS FROM 4 FT. TO 8 FT. LONG

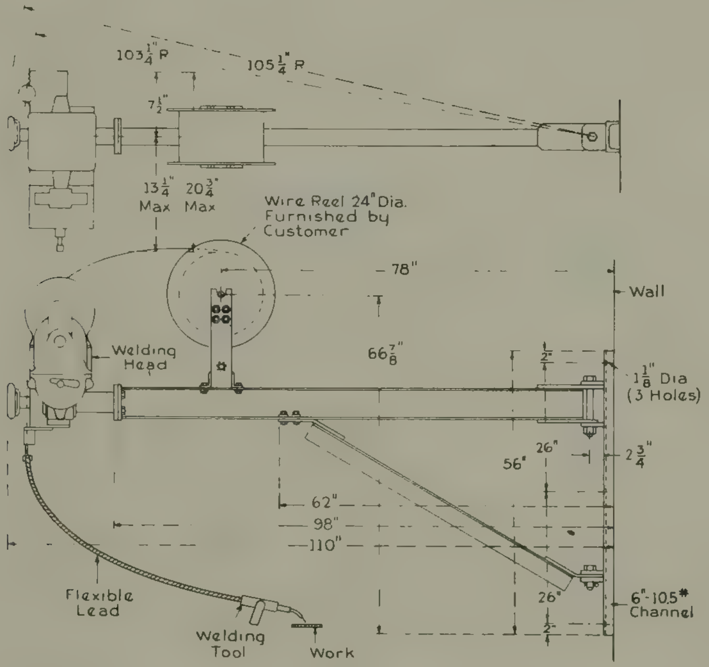


Fig. 192. OUTLINE OF JIB CRANE AND SEMI-AUTOMATIC WELDER

Fig. 190 shows a side seam welder for tanks up to 7 ft. in length and 3 ft. in diameter. Machines of this type for tanks up to 10 ft. in length and 5 ft. in diameter have been built and put in operation.

Fig. 192 is an outline of the jib crane support and semi-automatic welder.

Figs. 191 and 194 show a rolling device for welding circular seams of tanks or pipe. This device is used for rotating the tank and the welding heads are mounted separately.

Fig. 193 shows the make-up of the G-E welding electrode which is adapted for use with the G-E automatic arc welding machines.

Fig. 193. DETAILS OF G-E ARC WELDING ELECTRODE

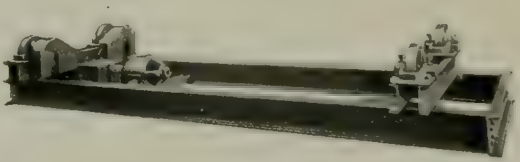


Fig. 194. TANK ROLLING MECHANISM FOR TANKS FROM 4 FT. TO 12 FT. LONG

## G-E WELDING SERVICE

Welding problems constantly arise and the successful use of the electric arc welding process depends in many cases on a solution of these problems. In many cases the prospective user is unacquainted with the technique of the process and must therefore experiment for some time before using arc welding in his production work. The General Electric Company maintains an arc welding school at its Schenectady Plant for the training of operators. (See Fig. 195.) The training course requires on the average about six or eight weeks, depending on the ability of the operator.

The General Electric Company aims to co-operate with users of its apparatus and others interested in using the arc welding process. G-E engineers will assist in solving welding problems. Welding data will be available upon request and when such information is not available, efforts will be made to obtain it. Consult your nearest G-E welding specialist.

Fig. 195. SECTION OF THE ARC WELDING SCHOOL OF THE GENERAL ELECTRIC COMPANY AT SCHENECTADY, N. Y.

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